Methodologies for Evaluating
Congestion Mitigation and Air Quality Improvement Projects

Maricopa Association of Governments

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INTRODUCTION

The purpose of the Congestion Mitigation and Air Quality Improvement (CMAQ) Program is to provide federal funding for projects designed to assist nonattainment and maintenance areas in complying with the National Ambient Air Quality Standards. The most recent federal guidance for the CMAQ program, effective October 20, 2008, indicates that the emission benefits and disbenefits for CMAQ project proposals should be quantified, if possible, for all pollutants for which the area is in nonattainment or maintenance status, including appropriate precursor emissions. The Maricopa Association of Governments (MAG) has developed methodologies for quantifying emission benefits and disbenefits and calculating the cost-effectiveness of proposed CMAQ projects. MAG has updated the CMAQ methodologies periodically since 1999 to address changes in federal guidance, new project types, and improved technical methods and assumptions.

The CMAQ methodologies dated March 31, 2001 were revised in September 2011 to add a new methodology for calculating the emission benefits and cost-effectiveness of natural gas and electric vehicles purchased with CMAQ funds. The paved road particulate emission factors have also been updated utilizing the latest (July 1, 2011) vehicle registration data provided by the Arizona Department of Transportation and data from the new MAG truck model.

Reviews of the CMAQ Methodologies

In 2002, MAG contracted with Sierra Research to review CMAQ methodologies and identify the most promising project evaluation techniques used by metropolitan planning organizations (MPOs) in the western U.S. On April 29, 2002, MAG conducted a half-day workshop describing the CMAQ methodologies in use by the western MPOs and the findings and recommendations of the Sierra Research study. In general, Sierra concluded that "the methods established by MAG for computing the cost-effectiveness of proposed CMAQ projects are easily the most sophisticated encountered in the review of western communities." The Sierra Research recommendations and input from the 2002 workshop were incorporated into the 2004 MAG CMAQ methodologies (MAG, 2004b).

On June 28, 2005, MAG conducted a second workshop to discuss additional revisions to the CMAQ methodologies. The input from this workshop was incorporated into the MAG CMAQ methodologies that were applied between August 2005 and April 2009 (MAG, 2005).

In 2008, MAG contracted with Sierra Research to review CMAQ approaches used elsewhere and recommend improvements to the 2005 MAG methodologies (MAG, 2008). The major findings of this study are summarized below.

(1) MAG's CMAQ methodologies adequately address the key issues in the latest federal transportation legislation (SAFETEA-LU, 2005). As recommended by SAFETEA-LU, MAG's CMAQ process includes an evaluation and prioritization of diesel retrofit projects, prioritizes projects based on cost-effectiveness, and allows funding of transportation systems management and operations projects that mitigate congestion and improve air quality.

(2) Like MAG, the California Air Resources Board (CARB) has eliminated carbon monoxide (CO) emissions from their calculations of cost-effectiveness for CMAQ projects.

(3) The level of detail used by the Texas Department of Transportation in evaluating CMAQ projects (TTI, 2007) is higher than currently required by the MAG methodologies. For example, the TTI methodology for ITS projects quantifies the emission reductions attributable to alleviating peak and off-peak recurrent and non-recurrent congestion. The TTI methodologies require extensive data collection on the part of entities requesting CMAQ funds. Sierra points out that the TTI methods are also used to quantify control measures for Texas SIPs.

(4) California communities can download automated database programs to quantify twelve types of CMAQ projects. Several other communities have established spreadsheets that automate the calculation of benefits and cost-effectiveness for project sponsors. Colorado has automated the procedures used to prepare the annual CMAQ reports. Sierra recommends that MAG consider automating its CMAQ methodologies.

(5) The MAG CMAQ methodologies should be updated to be consistent with assumptions in the Eight-Hour Ozone Plan (MAG, 2007a) and Five Percent Plan for PM-10 (MAG, 2007b).

(6) Sierra recommends that the local sources from which activity rates have been derived (e.g., On Board Bus and Household Travel Surveys, MAG Congestion Studies, Travel Demand Management Surveys, Maricopa County Trip Reduction Program Reports) be reviewed and updated where appropriate.

(7) The 2008 Sierra Research report concludes that: "Overall, the methods established by MAG for computing the cost-effectiveness of proposed CMAQ projects are still the most sophisticated of the states and communities surveyed, particularly for fugitive dust emission calculations."

As recommended by Sierra Research in (5), the emission factors for the ozone precursors, total organic gases (TOG) and nitrogen oxides (NOx), and for particulate matter less than or equal to 10 microns (PM-10) were updated in the 2009 CMAQ methodologies to be consistent with assumptions in the 2007 MAG Ozone and PM-10 Plans. On March 31, 2009, MAG conducted a workshop to discuss the findings of the latest Sierra Research review and proposed changes to the CMAQ methodologies. Input from workshop participants was incorporated into the 2009 methodologies.

To implement Sierra's recommendation (3), MAG contracted with Lee Engineering and Texas Transportation Institute (TTI) in 2010 to update the methodology for evaluating intelligent transportation system (ITS) projects (Lee/TTI, 2010). The ITS project evaluation methodology recommended by Lee/TTI has been implemented in the 2011 CMAQ methodologies.

Lee/TTI also suggested that the cost-effectiveness scores were too high for studies that will not reduce transportation emissions until the project is fully implemented (e.g., ITS strategic plans). In the past, these studies received emission reduction credit as though the project were fully implemented. In the future, they will receive five percent of the emission reduction benefit of the fully implemented project. Examples include stand-alone planning, engineering and design projects that are CMAQ-eligible.

The 2011 MAG CMAQ methodologies utilize emission factors derived from the latest EPA onroad mobile source emissions model, MOVES2010a. The activity rates from the "Transportation Demand Management, Annual Report" (Valley Metro, 2010) and "Trip Reduction Program, Annual Report" (MCAQD, 2009), have also been updated, as recommended in (6).

MAG conducted a workshop on December 6, 2010 to discuss the proposed changes to the 2011 CMAQ methodologies. Input from the workshop has been incorporated into the methodologies, as discussed in the Overview of Key Assumptions. Since Sierra Research concluded that MAG continues to have the most sophisticated methods among the states and communities surveyed, no other major changes have been made to the 2011 methodologies.

The 2011 CMAQ methodologies continue to assume that the priority weight for carbon monoxide (CO) is zero. Participants attending the MAG CMAQ workshop in 2005 suggested that a weight of zero be assigned to CO emissions when calculating cost-effectiveness and this was implemented in the 2005 methodologies. As indicated in the 2008 Sierra Research study, CARB also assigns a weight of zero to CO emissions when evaluating CMAQ projects. Since the Maricopa County area has not violated the CO standard since 1996 and monitored CO concentrations continue to decline, zeroing out the CO emissions in the CMAQ cost-effectiveness calculation remains appropriate. However, CO emission reductions must still be calculated for funded projects in the annual CMAQ report required by the Federal Highway Administration. If EPA lowers the National Ambient Air Quality Standard for CO in the future, the priority weight might may need to be changed. For these reasons, CO emissions are included in the equations and examples shown in this document, even though the priority weight is zero.

In the 2011 CMAQ methodologies, the priority weights for all other pollutants (i.e., TOG, NOx, and PM-10)[1] used in calculating cost-effectiveness are set to one[2]. Since the Maricopa County area is a nonattainment area for PM-10 and has not yet attained the more stringent eight-hour ozone standard of 0.075 ppm, it is appropriate to set equivalent priority weights for these three pollutants.

Seasonal adjustment factors are applied to the MOVES emission factors (i.e., TOG and NOx are

[1]PM-2.5 emissions are not included in the MAG CMAQ methodologies, because EPA designated the Phoenix-Mesa Metropolitan Statistical Area as an attainment area for PM-2.5 in September 2004.

[2]Emission reductions from CMAQ-eligible sweeping and paving projects located within four miles of a PM-10 monitor are assigned a priority weight of two.

divided by two to reflect the six-month ozone season)[3]. The use of MOVES emission factors will result in cost-effectiveness scores that differ from those calculated using MOBILE6 in previous versions of the MAG CMAQ methodologies.

CMAQ Project Review Process

Each year MAG programs available CMAQ funds. As part of the programming process, jurisdictions are requested, through the MAG Management Committee, MAG Transportation Review Committee, and MAG modal committees, to submit requests for federally funded projects. After the receipt of project requests, MAG evaluates CMAQ projects for possible inclusion in the Transportation Improvement Program. The MAG modal committees are furnished with the CMAQ assessment for project evaluation purposes. Recommendations from the MAG modal committees are forwarded to the Transportation Review Committee for programming consideration.

The CMAQ project assessment may be in the form of a quantitative analysis resulting from the methodologies or a qualitative evaluation (FHWA, 2008). Although MAG makes every effort to quantify the emission reduction impact of each project, FHWA guidance allows a qualitative evaluation to be made when a quantitative analysis is not possible. Qualitative evaluations may be based on a reasonable review of how a project or program will decrease emissions. Committed transportation control measures identified in the air quality plans receive priority in CMAQ project programming.

The CMAQ methodologies provide options for local input, while striving to keep the overall data requirements from being overly complex and burdensome. In general, agencies submitting CMAQ projects may provide local data to replace default values in any of the methodologies, as long as there is supporting written documentation. The values to be substituted and the supporting documentation (e.g., traffic engineering modeling; city-specific survey data) must accompany the request for CMAQ funding.

The methodologies included in this report were developed in response to FHWA guidance requiring the quantification of emission reductions for proposed CMAQ projects, whenever possible. Other potential project benefits such as human health, safety, land use, and congestion mitigation impacts are not addressed. It is also important to note that emission reductions and cost-effectiveness are not the only factors considered in evaluating and selecting candidates for CMAQ funding.

Overview of Key Assumptions

The methodologies for quantifying the emission reductions and cost-effectiveness of typical CMAQ projects are described below. In general, the methodologies estimate (1) emission reductions in kilograms per day, which are the sum of reductions in CO, TOG, NOx, and PM-10; and (2) the cost-

[3]A seasonal adjustment factor is not applied to PM-10, because violations of the PM-10 standard can occur at any time of year.

effectiveness of each project in dollars per metric ton of emissions reduced per year. Because the CMAQ methodologies use the new EPA onroad mobile source emissions model (MOVES) and the latest regional planning assumptions, the emission reductions may not be consistent with previous CMAQ analyses or air quality plans that used earlier models and assumptions. Most projects reduce CO, TOG, NOx and PM-10 emissions. In some cases (e.g., paving projects), only PM-10 emissions are reduced. If a proposed project combines two project types (e.g., paving a dirt road and adding a bicycle lane), the combined impact of the two portions of the project is included in the total emissions reduction.

MAG will run the latest version of the EPA Mobile Source Emission Simulator (MOVES) model to estimate CO, TOG, NOx, and PM-10[4] emission factors for the implementation year of the project. The emission factors will be based on the latest vehicle registrations and market shares of fuel types specific to Maricopa County. The default speed of area-wide traffic is assumed to be 30 miles per hour, unless specified otherwise in the methodologies.

The PM-10 emission rates for unpaved roads and alleys are derived from the AP-42 equation for unpaved roads (EPA, 2006). The AP-42 emission factors are used in calculating the benefits of projects that pave unpaved roads and alleys.

EPA has recently updated the AP-42 equation used to calculate PM-10 emission factors for particulate matter re-entrained into the air by vehicles traveling on paved roads (EPA, 2011). The new AP-42 emission factors are used in calculating the benefits of street sweeping, shoulder paving, and other projects that reduce paved road emissions. The AP-42 emission factors in the September 2011 CMAQ methodologies utilize July 1, 2011 vehicle registrations and outputs of the new MAG truck model to estimate vehicle weights on freeways and arterials in the PM-10 nonattainment area.

At the December 6, 2010 MAG CMAQ Methodologies Workshop, it was suggested that priority consideration or weighting be given to projects that solely address PM-10 emissions, when those project locations are in close proximity to a historically-exceeding air quality monitor. To respond to this suggestion, CMAQ-eligible street sweeping or paving (i.e., unpaved road, alley or shoulder) projects located within four miles[5] of a PM-10 monitor will be assigned a priority weight of two, rather than one, when PM-10 emission reductions are calculated.

Carbon monoxide emission reductions are calculated for the range of temperatures on the winter episode day in the EPA-approved carbon monoxide maintenance plan (MAG, 2003). As previously indicated, the priority weight for CO is zero and CO emission reductions are only calculated for the annual CMAQ report. No seasonal adjustment (i.e., division by four) is applied when estimating CO

[4]MOVES estimates emissions from tailpipe exhaust, tire wear and brake wear for PM-10.

[5]The modeling domain to be used in demonstrating attainment of the PM-10 standard during high wind conditions in the 2012 MAG Five Percent Plan for PM-10 includes emission sources that are located within four miles upwind of PM-10 monitors.

emissions for the annual CMAQ report.

TOG and NOx emissions are calculated for the range of temperatures on the June episode day in the Eight-Hour Ozone Plan (MAG, 2007a). In the calculation of total emission reductions and cost-effectiveness for projects requesting CMAQ funding, TOG and NOx reductions are divided by a seasonal factor of two to account for the six-month ozone season. No seasonal adjustment (i.e., division by two) is applied when estimating TOG and NOx emissions for the annual CMAQ report.

The temperatures used in estimating PM-10 emissions with MOVES represent hourly average temperatures in the year 2008. No seasonal factor is applied, because exceedances of the daily PM-10 standard can occur at any time of year. Because of the seasonal and priority weight assumptions discussed above, total emission reductions (i.e., the sum of CO, TOG, NOx and PM-10) for CMAQ projects do not represent an average day during the year.

In the CMAQ methodologies, the cost-effectiveness of a project is calculated by dividing the annualized CMAQ cost by the annual emission reduction. The annual emission reduction is obtained by converting the total weighted reduction in CO, TOG, NOx and PM-10 emissions in kilograms per day to metric tons per year. The CMAQ cost is amortized over the expected project life using a three percent discount rate, which represents the opportunity cost of using public dollars to fund a project, versus investing the same funds in a certificate of deposit earning three percent per year over the life of the project. The general approach for calculating cost-effectiveness and the discount rate is consistent with that used by the California Air Resources Board (CARB, 2005).

The remainder of this document describes the methodologies and assumptions used to estimate emission reductions and cost-effectiveness for typical CMAQ projects. The description of the methodology for each project type is divided into three sections. The first section describes the modeling methodology, assumptions, and defaults. The second lists the data that are requested from the entity proposing the project. If any of the required data are not provided, default assumptions are substituted. The third section provides the formulas used in the analyses. Data from the first and second sections are input to the formulas to estimate the emission reduction and cost-effectiveness of a proposed project. At least one example calculation is provided for each project type. The examples, representing generic CMAQ projects, are provided to demonstrate how the methodology will be applied. The emission reductions and cost-effectiveness calculated for actual CMAQ projects will be dependent upon local inputs and may vary substantially from the examples.

This document describes methodologies for the following project types, in alphabetical order: Bicycle and Pedestrian Facilities, Bus and Light Rail Projects, Diesel Retrofits and Anti-Idling Programs, Intersection Improvements (including Roundabouts), Natural Gas and Electric Vehicles, Park and Ride Facilities, Paving Projects, PM-10 Efficient Street Sweepers, Rideshare Programs, Traffic Flow Improvements, Trip Reduction Program,[6] and Vanpool Vehicles.

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[6] In 2010, the Ozone Education and Telework Programs, which were previously evaluated as separate CMAQ projects, were merged with the Regional Rideshare Program.

These represent the most common CMAQ project types in the MAG region. CMAQ-eligible projects that do not fall into one of these categories will also be quantified, if feasible, on a case-by-case basis. If CMAQ funding for one phase (e.g., planning or design) of an eligible project is requested, the emission reduction benefit will be calculated for the first year that the project is expected to be completed. If additional CMAQ funds have been or will be requested to complete a project (e.g., a light rail segment), the requesting entity will be asked to estimate the total CMAQ funds to be used in calculating the cost-effectiveness of the project.

Application of Methodologies

The CMAQ methodologies calculate daily emission reductions and cost-effectiveness, measures that are used in prioritizing projects that are candidates for future CMAQ funds. The methodologies are also used to quantify daily emission reductions for annual CMAQ reports submitted to FHWA. If emission reduction credit for a CMAQ-funded project in the Transportation Improvement Program has not been taken in a State Implementation Plan (SIP), the benefits of the project may also be used in transportation conformity. Since the annual CMAQ report and conformity analyses require emission reductions by individual pollutant, the priority weights (*w1, w2, w3, w4*) and seasonality factors (e.g., dividing VOC and NOx by two) are not used in these applications.

BICYCLE AND PEDESTRIAN FACILITIES

"Encouragement of Bicycle Travel" and "Development of Bicycle Travel Facilities" are committed control measures in the Serious Area CO Plan (MAG, 2001) and Serious Area PM-10 Plan (MAG, 2000a). Bicycle facilities have the potential to reduce commute and other non-recreational trips. Bicycle paths are facilities which are physically separated from motor vehicle traffic. Bicycle lanes are striped for preferential or exclusive use of bicycles. CO, TOG, NOx, and PM-10 emission reductions occur when bicycle trips replace single occupant vehicle trips.

"Encouragement of Pedestrian Travel" is also a committed control measure in the MAG Serious Area CO and PM-10 Plans. Pedestrian facilities provide or improve pedestrian access. Emissions are reduced when vehicle trips are replaced by walking.

The CO, TOG, NOx, and PM-10 emission factors are calculated for the implementation year of the project. The project life for bicycle lanes on roads or shoulders will be twenty years; for sidewalks, bicycle paths, and pedestrian paths, thirty years; and for overpasses and underpasses, fifty years.

The number of vehicles replaced by bicycle or pedestrian trips will be estimated based on the average weekday traffic (***ADT***) on the adjacent or nearest parallel arterial to the bicycle or pedestrian facility, where the ADT is provided by the entity requesting CMAQ funding for the project. The maximum allowable ADT will be 30,000 vehicle trips per weekday.[7] The weekday ADT will be converted to annual average daily traffic (***AADT***) by multiplying by 0.93. The vehicles reduced will be calculated

[7]Derived from CARB, 2005.

by multiplying the AADT by the sum of the adjustment factor (***A***) and the activity center credit (***C***).

The adjustment factor (***A***) in Table 1 is dependent upon the length of the bicycle/pedestrian project and the AADT on the road parallel to the bicycle/pedestrian project. Given the relative importance of bridges and underpasses that connect bicycle/pedestrian paths, the adjustment factor used for bridges and underpasses will be based on the sum of the lengths of the two paths connected.

The usefulness of a bicycle/pedestrian facility is also dependent upon its location. Usage estimates for bicycle/pedestrian facilities will take into consideration the number of activity centers near the proposed facility. The credit (***C***) for activity centers located along a bicycle/pedestrian facility is shown in Table 2.

Table 1. Adjustment Factors[8]

ANNUAL AVERAGE DAILY TRAFFIC (AADT)	LENGTH OF PROJECT (one direction)	**ADJUSTMENT FACTOR (*A*)**
AADT ≤ 12,000 vehicles per day	≤ 1 mile	0.0019
	> 1 mile and ≤ 2 miles	0.0029
	> 2 miles	0.0038
12,000 < AADT≤ 24,000 vehicles per day	≤ 1 mile	0.0014
	> 1 mile and ≤ 2 miles	0.0020
	> 2 miles	0.0027
AADT > 24,000 vehicles per day	≤ 1 mile	0.0010
	> 1 mile and ≤ 2 miles	0.0014
	> 2 miles	0.0019

Table 2. Activity Center Credits[9]

Examples of Activity Centers: bank, church, hospital, health care facility, park and ride lot, office park, post office, public library, shopping area or grocery store, schools, university or junior college.

Number of activity centers	**ACTIVITY CENTER CREDIT (*C*)**	
	Within ½ mile	Within ¼ mile
at least three	0.0005	0.001
more than three but less than seven	0.001	0.002
seven or more	0.0015	0.003

[8]Adapted from CARB, 2005.

[9]Ibid.

The VMT reduced by bicycle/pedestrian facilities is estimated by multiplying the vehicles reduced by the average trip length. Consistent with assumptions in MAG transportation modeling concerning pedestrian trips to transit centers, a pedestrian trip length of one-half mile will be assumed. Based on data in *Bicycle Demand and Benefit Model* (Alta Transportation Consulting, 2000), an average bicycle trip length of four miles will be assumed. For multi-use paths, it will be assumed that half of the trips are bicycle and half are pedestrian. Therefore, an average trip length of 2.25 miles will be applied for multi-use paths.

The MOVES model will be run to estimate CO, TOG, NOx, and PM-10 emission factors for light duty vehicles, assuming a speed of 30 miles per hour. The off-network (Road Type 1) emission factors in grams per vehicle per hour ($\boldsymbol{OFF_{CO}}$, $\boldsymbol{OFF_{TOG}}$, $\boldsymbol{OFF_{NOx}}$, $\boldsymbol{OFF_{PM}}$) will be multiplied by the number of vehicles reduced by bicycle/pedestrian trips.[10] The arterial (Road Types 3 and 5) emission factors in grams per mile ($\boldsymbol{ARF_{CO}}$, $\boldsymbol{ARF_{TOG}}$, $\boldsymbol{ARF_{NOx}}$) will be multiplied by the VMT reduced by the bicycle/pedestrian trips.

For PM-10, the paved road emission factor for arterials (***PEF***) will be added to the arterial emission factor ($\boldsymbol{ARF_{PM}}$) before being multiplied by the VMT reduced by bicycle/pedestrian facilities. The paved road emission factor for all arterials, based on the new AP-42 equation, is 0.34 grams per mile.

If a bike lane project includes shoulder paving, additional credit for reducing PM-10 emissions will be assigned to the project. The emission factors and equations used in calculating PM-10 reductions due to shoulder paving are described in the section on Paving Projects.

The formulas below are used to calculate the emission reductions and cost-effectiveness for bicycle and pedestrian facilities.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Average weekday traffic (***ADT***) on the nearest parallel arterial.
- Number of activity centers (i.e. bank, church, hospital, health care facility, light rail station, park and ride lot, office park, post office, public library, shopping area, grocery store, university or junior college) within ¼ mile and ½ mile of the bicycle/pedestrian project.
- Length of bicycle/pedestrian path (for a bridge/underpass; the combined length of the paths connected by the bridge/underpass).
- If shoulder paving is part of the project, whether the project is located within four miles of a PM-10 monitor.

Formulas:

$$\textit{Vehicles Reduced } (\boldsymbol{VR}) = \boldsymbol{AADT} * (\boldsymbol{A} + \boldsymbol{C})$$

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[10]It is assumed that each bicycle/pedestrian trip reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) for one vehicle hour between 6 a.m. and 6 p.m.

where: ***A*** = the adjustment factor from Table 1
C = the activity center credit from Table 2
AADT = the ***ADT*** on the adjacent or nearest parallel arterial (maximum = 30,000 ADT), multiplied by 0.93

$$\textit{VMT Reduced } (\boldsymbol{VMTR}) = \boldsymbol{VR} * \boldsymbol{trip\ length}$$

where: ***trip length*** = the length of a bicycle trip is assumed to be 4.0 miles and the length of a pedestrian trip is assumed to be 0.5 miles. For a multi-use path, it is assumed that the average trip length is 2.25 miles.

$$\textit{Daily Emissions Reduction} = [VR * (\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + w4 * OFF_{PM})] +$$

$$[VMTR * (\frac{w1 * ARF_{CO}}{4} + \frac{w2 * ARF_{TOG}}{2} + \frac{w3 * ARF_{NOx}}{2} + w4 * (ARF_{PM} + PEF))] * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***OFF*** = the off-network light duty vehicle emission factor for each pollutant
ARF = the arterial light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for non-freeways (0.35 g/mi)
w1-w4= weighting factors for CO, TOG, NOx, and PM-10, respectively

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}} - 1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years for bicycle lanes on a road or shoulder; 30 years for a sidewalk, bicycle path, or pedestrian path; and 50 years for an overpass or underpass.

$$\textit{Cost-Effectiveness} = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{\textit{Daily Emissions Reduction} * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

A city proposes to build a 1.5 mile bike lane by paving an unpaved shoulder with curb and gutter in 2015 at a total cost of $650,000, where $65,000 will be paid with local funds. The bike lane will be adjacent to an arterial outside the Salt River Area with average weekday traffic of 18,000 vehicles per day. There are three activity centers (a grocery store, a library, and a park and ride lot) less than one-quarter mile from the path. There are four additional activity centers (two office parks, a church, and a post-office) between one-quarter and one-half mile from the proposed project for a total of seven activity centers within one-half mile. The shoulder paving project is not located within four miles of any PM-10 monitor.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $585,000.
- Project length (***miles***) = 1.5 miles.
- Average weekday traffic (***ADT***) on adjacent arterial = 18,000.
- Activity centers within ¼ mile = 3 OR activity centers within ½ mile = 7.
- The shoulder paving with curb and gutter is not located within four miles of a PM-10 monitor.

Calculations:

The primary Adjustment Factor (**A**) is derived from Table 1. Since the ***ADT*** is 18,000, the ***AADT*** is 16,740 (0.93 x 18,000). From Table 1, the adjustment factor for a path adjacent to a roadway with between 12,000 and 24,000 ***AADT*** and between one and two miles in length is 0.0020. The Activity Center Credit (**C**) is obtained from Table 2. There are two choices of activity center credit for this project, since there are three activity centers within one-quarter mile (0.001) and seven centers within one-half mile (0.0015). The higher value, 0.0015, is chosen. Additional credit will be given to the project for reducing PM-10 by paving an unpaved shoulder. The emission reduction credit for paving an unpaved shoulder with curb and gutter on one-side of the road is 0.27 grams per vehicle mile of travel (see the section on Paving Projects).

$$\textit{Vehicles Reduced } (\boldsymbol{VR}) = 16{,}740 * (0.0020 + 0.0015) = 59 \ \frac{\textit{vehicles}}{\textit{day}}$$

$$\textit{VMT Reduced } (\boldsymbol{VMTR}) = 59 * 4.0 = 236 \ \frac{\textit{vehicle-miles}}{\textit{day}}$$

$$\textit{Daily Emissions Reduction for Bike Lane} = [59 * (\frac{0.0*4.16}{4} + \frac{1.0*0.48}{2} + \frac{1.0*0.26}{2} + (1.0*0.004)] +$$

$$[236 * (\frac{0.0*2.04}{4} + \frac{1.0*0.13}{2} + \frac{1.0*0.42}{2} + (1.0*(0.04+0.35))] * \frac{1}{1000} = 0.18 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$Daily\ Emissions\ Reduction\ for\ Paving\ Shoulder = (1.0*0.27*16{,}740*1.5)*\frac{1}{1000} = 6.78\ \frac{kilograms}{day}$$

$$Total\ Daily\ Emissions\ Reduction = 0.18 + 6.78 = 6.96\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$Cost\text{-}Effectiveness = \frac{0.0672 * 585{,}000 * 1000}{6.96 * 365} = 15{,}475\ \frac{dollars}{metric\ ton}$$

BUS AND LIGHT RAIL PROJECTS

"Expansion of Public Transportation Programs" and "Mass Transit Alternatives" are committed control measures in the MAG Serious Area CO and PM-10 Plans. These measures reduce CO, TOG, NOx, and PM-10 emissions by reducing the number of vehicles and vehicle miles of travel (VMT) driven with a single occupant.

New Bus Service

Bus service on new routes and increased frequency on existing bus routes provide a new level of service and reduce vehicles and VMT. The daily emissions reduction attributable to the new bus service will be estimated based on the difference between the emissions from the light duty vehicles replaced by the bus and the sum of the bus emissions from the new service and vehicle emissions from people driving to access the bus.

The vehicle miles of travel replaced ($\boldsymbol{VMT_{REP}}$) by the new bus service will be estimated based on the fraction of riders on the bus who drove to their destination prior to introduction of the new bus service ($\boldsymbol{F_1}$). This fraction will be multiplied by total bus riders and the average trip length replaced by the bus service (***trip length$_1$***). The VMT replaced by bus trips will be multiplied by onroad (Road Types 2-5) light duty vehicle emission factors from MOVES and paved road PM-10 emission factors from AP-42 to estimate the emissions from VMT replaced by transit.

The vehicles reduced (***VR***) by the new bus service will be estimated as the number of riders who previously drove to their destination minus the number of riders that drove to the bus. The vehicles reduced will be multiplied by the off-network (Road Type 1) light duty vehicle emission factors in grams per vehicle per hour from MOVES.[11]

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[11]It is assumed that each bus passenger that previously drove to their destination reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

The VMT added (***VMT_{ADD}***) by people driving to reach the new transit service will be estimated based on the fraction of riders on the bus who drive to transit (***F_2***). This fraction will be multiplied by total bus riders and the average trip length to reach transit (***$trip\ length_2$***). The VMT added by vehicle trips to reach transit will be multiplied by light duty vehicle emission factors from MOVES and paved road PM-10 emission factors from AP-42 to estimate the light duty emissions added by vehicle trips to reach transit.

The emissions produced by the bus (***BE***) are equal to the number of miles driven daily by the bus multiplied by the on-road exhaust emission factor plus the off-network emissions for the bus plus the paved road PM-10 emission factor for the bus. The paved road dust emission factor for a bus (1.74 grams per mile) has been calculated, assuming an average vehicle weight of 18 tons. The off-network and exhaust emission factors for buses are estimated using MOVES. Based on 2011 RPTA data, a typical bus travels 121 miles per annual average day (***VMT_{BUS}***).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Funding***
- Fraction of riders who previously drove to their destination in a single occupant vehicle (***F_1***). For example, if 75 of 100 bus riders would have driven an SOV to their destination, F_1 would equal 0.75. Default = 0.50 (CARB, 2005).
- Fraction of riders who drive to reach transit (***F_2***). For example, if 5 of 100 riders of the new bus drive to reach the bus, F_2 would equal 0.05. Default = 0.03 (RPTA, 2008).
- Average length of vehicle trips (***$trip\ length_1$***). Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, Feb.15, 2005).
- Total daily ridership of each new bus (***R***). For example, if the new bus is expected to carry 400 passengers per day, R would equal 400. Default = 284 (Based on 2011 RPTA data).
- Average length of trip driving from home to transit (***$trip\ length_2$***). Default = 5 miles (Valley Metro, 2001).

Formulas:

$$VMT\ Replaced\ (\boldsymbol{VMT_{REP}}) = R * F_1 * trip\ length_1$$

$$VMT\ added\ (\boldsymbol{VMT_{ADD}}) = R * F_2 * trip\ length_2$$

$$Vehicles\ Reduced\ (\boldsymbol{VR}) = R * (F_1 - F_2)$$

where: $\boldsymbol{R}$ = the average ridership on the bus per operating day

$\boldsymbol{F_1}$ = the fraction of riders on the bus who previously drove a single occupant vehicle

$\boldsymbol{trip\ length_1}$ = the average trip length replaced for each rider who previously drove

$\boldsymbol{F_2}$ = the fraction of riders who drive to transit

$\boldsymbol{trip\ length_2}$ = the average trip length driven to transit

$$Onroad\ Vehicle\ Emissions\ Reduced\ (\boldsymbol{VER_1}) = (\boldsymbol{VMT_{REP}} - \boldsymbol{VMT_{ADD}})*(\frac{w1*ONF_{CO}}{4}+\frac{w2*ONF_{TOG}}{2}+\frac{w3*ONF_{NOx}}{2}+$$

$$(w4 * (ONF_{PM}+PEF)) * \frac{1}{1000} = \frac{kilograms}{day}$$

$$Off\text{-}network\ Vehicle\ Emissions\ Reduced\ (\boldsymbol{VER_2}) = \boldsymbol{VR}*(\frac{w1*OFF_{CO}}{4}+\frac{w2*OFF_{TOG}}{2}+\frac{w3*OFF_{NOx}}{2}+$$

$$w4 * OFF_{PM}) * \frac{1}{1000} = \frac{kilograms}{day}$$

where: $\boldsymbol{VMT_{REP}}$ = the vehicle travel replaced by bus service

$\boldsymbol{VMT_{ADD}}$ = the VMT added as a result of trips driven to reach transit

ONF = the onroad light duty vehicle emission factor for each pollutant

OFF = the off-network light duty vehicle emission factor for each pollutant

PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)

w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$Bus\ Emissions(\boldsymbol{BE}) =$$

$$(\frac{w1*BEF_{CO}}{4}+\frac{w2*BEF_{TOG}}{2}+\frac{w3*BEF_{NOx}}{2}+ (w4*(BEF_{PM}+PEF_{BUS})))*VMT_{BUS}*\frac{1}{1000} = \frac{kilograms}{day}$$

where: ***BEF*** = the onroad bus emission factor for each pollutant (includes tire and brake wear for PM-10)

$\boldsymbol{PEF_{BUS}}$ = the paved road emission factor for a bus (1.74 g/mi)

$\boldsymbol{VMT_{BUS}}$ = the annual average daily bus VMT (121)

$$Daily\ Emissions\ Reduction = \boldsymbol{VER_1} + \boldsymbol{VER_2} - \boldsymbol{BE} = \frac{kilograms}{day}$$

$$\text{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{life}\,(i)}{(1+i)^{life}-1}$$

where: $\boldsymbol{i}$ = discount rate of 3 percent
life = effectiveness period of 12 years (CARB, 2005)

$$\text{Cost-Effectiveness} = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{\text{Daily Emissions Reduction} * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

New Bus Service **EXAMPLE**

A city proposes to purchase a diesel bus to start a new bus route in 2015. The cost of the bus is $320,000. The city proposes to pay $32,000 and requests $288,000 of CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $288,000.
- Fraction of riders who would drive in a single occupant vehicle to their destination ($\boldsymbol{F_1}$) = 0.50.
- Fraction of riders who drive in a single occupant vehicle to reach transit ($\boldsymbol{F_2}$) = 0.03.
- Average length of vehicle trips (***trip length***$_1$) = 10.6 miles.
- Total daily ridership on the new bus ($\boldsymbol{R}$) = 284.
- Average length of trip from home to transit (***trip length***$_2$) = 5 miles.

Calculations:

$$\boldsymbol{VMT_{REP}} = 284 * 0.5 * 10.6 = 1{,}505$$

$$\boldsymbol{VMT_{ADD}} = 284 * 0.03 * 5 = 43$$

$$\boldsymbol{VR} = 284 * (0.5 - 0.03) = 133$$

$$\boldsymbol{VER_1} = (1{,}505 - 43) * (\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.26)) * \frac{1}{1000} = 0.83\ \frac{kilograms}{day}$$

$$\boldsymbol{VER_2} = 133 * (\frac{0.0*4.16}{4} + \frac{1.0*0.48}{2} + \frac{1.0*0.26}{2} + (1.0*0.004)) * \frac{1}{1000} = 0.05 \ \frac{kilograms}{day}$$

$$\boldsymbol{BE} = 121 * \ (\frac{0.0*1.71}{4} + \frac{1.0*0.40}{2} + \frac{1.0*5.42}{2} + (1.0*(0.40+1.74)) * \frac{1}{1000} = 0.61 \ \frac{kilograms}{day}$$

$$Daily\ Emissions\ Reduction = 0.83 + 0.05 - 0.61 = 0.27 \ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{\mathbf{12}} * (0.03)}{(1+0.03)^{\mathbf{12}} - 1} = 0.1005$$

$$Cost\text{-}Effectiveness = \frac{0.1005 * 288{,}000 * 1000}{0.27 * 365} = 293{,}699 \ \frac{dollars}{metric\ ton}$$

New Light Rail Service

Light rail represents another alternative mode to single occupant vehicle travel. Light rail service decreases emissions by reducing vehicles and vehicle miles of travel. The daily emissions reduction attributable to the provision of new rail service or the improvement of existing service will be based on the estimated number of light rail passengers who previously drove in single occupant vehicles. Emissions from light rail passengers driving to access the light rail stations will be deducted from the benefit.

The MOVES model will be run for the CMAQ funding year to estimate the onroad light duty vehicle emission factors (Road Types 2-5) for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, *and* ONF_{PM}). The paved road emission factor for all roads (0.26 grams per mile) will be added to ONF_{PM}. These emission factors will be multiplied by the reduction in vehicle miles of travel. MOVES will also be run to estimate the off-network emission factors (OFF_{CO}, OFF_{TOG}, OFF_{NOx}, *and* OFF_{PM}), which will be multiplied by the reduction in vehicles.[12] These emission reductions will be summed to estimate the total emissions benefit of the Light Rail project.

[12]It is assumed that each light rail passenger that previously drove to their destination reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Funding (total for the rail segment being funded)***.
- Fraction of riders who previously drove to their destination (***F_1***). For example, if 75 of 100 rail riders drove vehicles to their destination before introduction of the new rail service, F_1 would equal 0.75. Default = 0.50 (CARB, 2005).
- Fraction of riders who drive to reach rail (***F_2***). For example, if 5 of 100 riders drive to reach the rail line, F_2 would equal 0.05. Default = 0.03 (RPTA, 2008)
- Average length of vehicle trips (***trip length$_1$***). Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, Feb.15, 2005)
- Total annual average daily ridership on the rail line (***R***). For example, if the new line is expected to carry 30,000 passengers per annual average day, R would equal 30,000.
- Average length of trip driving from home to rail (***trip length$_2$***). Default = 5 miles (Valley Metro, 2001).

Formulas:

$$VMT\ Replaced\ (\boldsymbol{VMT_{REP}}) = R*F_1*trip\ length_1$$

$$VMT\ added\ (\boldsymbol{VMT_{ADD}}) = R*F_2*trip\ length_2$$

$$Vehicles\ Reduced\ (\boldsymbol{VR}) = R*(F_1 - F_2)$$

where: ***R*** = the ridership on the rail segment per annual average day
F_1 = the fraction of rail riders who previously drove in a single occupant vehicle
trip length$_1$ = the average trip length replaced for each rider who previously drove
F_2 = the fraction of riders who drive to the rail station
trip length$_2$ = the average trip length driven to the rail station

$$Onroad\ Vehicle\ Emissions\ Reduced\ (\boldsymbol{VER_1}) = (\boldsymbol{VMT_{REP}} - \boldsymbol{VMT_{ADD}})*(\frac{w1*ONF_{CO}}{4}+\frac{w2*ONF_{TOG}}{2}+\frac{w3*ONF_{NOx}}{2}+$$

$$(w4*(ONF_{PM}+PEF))*\frac{1}{1000} = \frac{kilograms}{day}$$

$$Off\text{-}network\ Vehicle\ Emissions\ Reduced\ (\boldsymbol{VER_2}) = \boldsymbol{VR}*(\frac{w1*OFF_{CO}}{4}+\frac{w2*OFF_{TOG}}{2}+\frac{w3*OFF_{NOx}}{2}+$$

$$w4*OFF_{PM})*\frac{1}{1000} = \frac{kilograms}{day}$$

$$\textit{Daily Emissions Reduction} = \boldsymbol{VER_1} + \boldsymbol{VER_2} = \frac{kilograms}{day}$$

where: $\boldsymbol{VMT_{REP}}$ = the vehicle travel replaced by the rail service
$\boldsymbol{VMT_{ADD}}$ = the VMT added as a result of trips driven to the rail station
ONF = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{life}\ (i)}{(1+i)^{life}\ -1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$\textit{Cost-Effectiveness} = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{\textit{Daily Emissions Reduction} * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

New Light Rail Service **EXAMPLE**

In 2013, Valley Metro Rail (VMR) requests $4,000,000 in CMAQ funds to augment the cost of constructing an additional 20-mile segment of the light rail system. VMR estimates that a total of $20 million in supplemental CMAQ funds will be needed to complete the new light rail segment. Transit modeling indicates that 30,000 passengers will ride the new segment on an annual average day during the first full year of operation in 2015.

Inputs Required from Entity Requesting CMAQ Funds:

- ***Total CMAQ Cost for new segment*** = $20,000,000.
- Number of light rail passengers per average weekday ***(R)*** = 30,000.

- Fraction of riders who previously drove to their destination in an SOV ($\boldsymbol{F_1}$) = 0.50.
- Average length of vehicle trips diverted to rail (***trip length$_1$***) = 10.6 miles.
- Fraction of riders who drive to the rail station ($\boldsymbol{F_2}$) = 0.03.
- Average length of trips driven to the rail station (***trip length$_2$***) = 5 miles.

Calculations:

$$VMT\ Replaced\ (\boldsymbol{VMT_{REP}}) = 30{,}000 * 0.5 * 10.6 = 159{,}000$$

$$VMT\ added\ (\boldsymbol{VMT_{ADD}}) = 30{,}000 * 0.03 * 5.0 = 4{,}500$$

$$Vehicles\ Replaced\ (\boldsymbol{VR}) = 30{,}000 * (0.5 - 0.03) = 14{,}100$$

$$VER_1 = (159{,}000 - 4{,}500) * (\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.26))) * \frac{1}{1000} = 87.29\ \frac{kg}{day}$$

$$VER_2 = 14{,}100 * (\frac{0.0*4.16}{4} + \frac{1.0*0.48}{2} + \frac{1.0*0.26}{2} + (1.0*0.004)) * \frac{1}{1000} = 5.27\ \frac{kg}{day}$$

$$Daily\ Emissions\ Reduction = 87.29 + 5.27 = 92.56\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$Cost\text{-}Effectiveness = \frac{0.0672 * 20{,}000{,}000 * 1000}{92.46 * 365} = 39{,}825\ \frac{dollars}{metric\ ton}$$

DIESEL RETROFITS AND ANTI-IDLING PROGRAMS

FHWA has indicated that retrofits for diesel engines and anti-idling programs for diesel trucks are eligible for CMAQ funding if they reduce emissions primarily in a nonattainment or maintenance area (FHWA, 2008). Federal transportation legislation also authorizes use of CMAQ funds for these types of projects (SAFETEA-LU, 2005).

The term diesel retrofit includes any technology or system that achieves emission reductions beyond that required by the EPA regulations at the time of new engine certification (EPA, 2007). Diesel retrofit projects may include replacement of high-emitting vehicles/equipment with cleaner vehicles/equipment (including hybrid or alternative fuel models); repowering or engine replacement; rebuilding the engine to a cleaner standard; purchase and installation of advanced emissions control technologies (such as particulate matter traps or oxidation catalysts); or the use of a cleaner fuel. CMAQ funds may be used to retrofit onroad diesel vehicles or nonroad diesel vehicles/engines used in construction. Projects that retrofit diesel engines can significantly reduce tailpipe emissions; the pollutants reduced will vary depending upon the technology or system that is installed. For example, installation of catalyzed diesel particulate filters or diesel oxidation catalysts will reduce particulate matter (PM-10 and PM-2.5), while replacing an older engine with newer technology will reduce CO, TOG, NOx, and PM-10 emissions.

In addition, CMAQ may be used to fund the capital costs of anti-idling programs, including advanced truck stop electrification projects and installation of auxiliary power units (APUs) on heavy duty diesel trucks. Heavy duty diesel trucks typically idle 6-10 hours per day to power the sleeper cab air conditioning, heating, and appliances (FHWA, 2009). Projects that reduce idling of diesel vehicles can significantly reduce tailpipe emissions of NOx and PM-10.

Diesel Retrofits

CMAQ projects would typically involve retrofitting diesel engines manufactured between 1990 and 2007. If the retrofits are for onroad vehicles, MOVES will be run to estimate exhaust emission rates at 30 mph for each model year heavy duty diesel vehicle that is being retrofitted. Since ultra low sulfur fuel has been required for onroad diesel vehicles nationwide since October 2006, the sulfur level in the diesel fuel will be set at 15 ppm in MOVES. If the retrofits are occurring to nonroad engines, the latest version of the EPA NONROAD model will be run to determine the emission rates for each model year engine that is being retrofitted and the diesel sulfur level will be set to 15 ppm.[13] The emission rates for the non-retrofitted vehicles/engines will be multiplied by the average annual vehicle miles traveled by all vehicles of that model year.

For vehicles/engines being retrofitted with diesel oxidation catalysts, the PM-10 exhaust emissions will be reduced by 30 percent. If the vehicles/engines are being retrofitted with catalyzed diesel particulate filters, the PM-10 exhaust emissions will be reduced by 90 percent (EPA, 2007).

If the engines are being replaced or rebuilt, the emissions of CO, TOG, NOx and PM-10 from the older model year vehicle/engine will be compared with the emissions generated by a heavy duty diesel onroad vehicle (using MOVES) or a nonroad engine (using NONROAD) manufactured in 2015. The difference between the emissions for the older model year and 2015 will represent the benefit of the diesel retrofit project. It is expected that the vehicles or engines that are retrofitted will be kept in service for at least five years.

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[13]EPA ultralow sulfur fuel standards became effective for nonroad engines in June 2010.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Model year(s) of the vehicles to be retrofitted.
- Average annual mileage traveled by the vehicles being retrofitted.

Formulas:

$$\textit{Emissions Before Retrofit } (EBR_i) = \boldsymbol{VMT_i} * \left(\frac{w1*BEF_{CO}}{4} + \frac{w2*BEF_{TOG}}{2} + \frac{w3*BEF_{NOx}}{2} + (w4*BEF_{PM10})\right)$$

$$\textit{Emissions After Retrofit } (EAR) = \sum \boldsymbol{VMT_i} * \left(\frac{w1*AEF_{CO}}{4} + \frac{w2*AEF_{TOG}}{2} + \frac{w3*AEF_{NOx}}{2} + (w4*AEF_{PM10})\right)$$

where: $\boldsymbol{VMT_i}$ = the annual miles driven by vehicles of model year *i*

BEF = the heavy duty diesel emission factor for each pollutant in model year *i,* assuming ultra-low sulfur fuel (15 ppm) for onroad vehicles or low sulfur fuel (500 ppm) for nonroad vehicles/engines

AEF = the onroad heavy duty diesel factor for each pollutant in model year 2015

w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$\textit{Daily Emissions Reduction} = \left(\sum \boldsymbol{EBR_i} - \boldsymbol{EAR}\right) * \frac{1}{1000} * \frac{1}{365} = \frac{\textit{kilograms}}{\textit{day}}$$

where: **1/365** = factor to convert annual emissions to daily emissions

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}} - 1}$$

where: ***i*** = discount rate of 3 percent

life = effectiveness period of 5 years

$$\textit{Cost-Effectiveness} = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ \textit{Cost} * 1000}{\textit{Daily Emissions Reduction} * 365} = \frac{\textit{dollars}}{\textit{metric ton}}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

A city requests $160,000 in FY 2015 CMAQ funds to retrofit 40 heavy duty diesel vehicles in the onroad municipal fleet with catalyzed diesel particulate filters. The city will provide a $10,000 cash match for the project. The average model year of the vehicles to be retrofitted is 2005. The average annual miles driven by each vehicle is 20,000. The city commits to use the retrofitted vehicles for at least five more years. MOVES estimates that the PM-10 exhaust emissions for a 2005 heavy duty vehicle running on ultra-low sulfur diesel fuel is 1.11 grams per mile. Because particulate filters are being installed, the PM-10 exhaust emissions from the vehicle fleet will be reduced by 90 percent.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $160,000.
- Average model year = 2005.
- Average annual miles driven per vehicle = 20,000.

Calculations:

$$\textit{Daily Emissions Reduction} = 20{,}000 * 40 * (1.00 * 1.11) * 0.90 * \frac{1}{1000} * \frac{1}{365} = 2.19\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 160{,}000 * 1000}{2.19 * 365} = 43{,}716\ \frac{\textit{dollars}}{\textit{metric ton}}$$

<u>Diesel Anti-Idling Programs</u>

Projects that reduce idling emissions from heavy duty diesel vehicles in a nonattainment or maintenance area are eligible for CMAQ funding (FHWA, 2008). One example would be a public-private partnership to implement a truck stop electrification project. Emissions will be reduced because trucks will turn off their engines and receive compartment cooling/heating and other services (cable TV, high speed internet) from the electric stalls during rest stops.

Another example of an anti-idling program would be the installation of auxiliary power units (APUs) on a fleet of diesel trucks that operate primarily within a nonattainment or maintenance area. APUs are mobile idle reduction technology that provides air conditioning, heat, and power for sleeper cab appliances, as well as battery charging and start assist for the main engine. They can be diesel or battery powered or a combination of both (FHWA, 2009).

To quantify the benefit of an anti-idling project, MOVES will be run to estimate extended idling emission factors for NOx and PM-10 for heavy duty diesel vehicles in the year of project implementation. The MOVES emission rates in grams per vehicle per hour will be multiplied by the estimated daily reduction in idling hours. The resultant emissions will represent the reduction benefit of a truck stop electrification project. For a CMAQ project involving auxiliary power units, the benefit will be calculated as the difference between the idling emissions for diesel trucks before and after installation of the APUs.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Diesel vehicle idling hours reduced on an annual average day (***IR***).

Formulas:

$$Daily\ Emissions\ Reduction = \boldsymbol{DIR} * (w3*\frac{DIEF_{NOx}}{2}) + (w4*DIEF_{PM10})) * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***DIR*** = diesel vehicle idling hours reduced by the project on an annual average day
DIEF = the heavy duty diesel extended idling emission factor (in grams per vehicle per hour) for NOx and PM-10

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+\boldsymbol{i})^{\boldsymbol{life}}\ (\boldsymbol{i})}{(1+\boldsymbol{i})^{\boldsymbol{life}}\ -1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 5 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF}*\boldsymbol{CMAQ}\ Cost*1000}{Daily\ Emissions\ Reduction*365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Truck Stop Electrification — EXAMPLE

A city located within the PM-10 nonattainment area would like to enter into a legal agreement with a private firm to build 50 electrified stalls at a truck stop along an Interstate facility in the city limits. The total cost of the project is estimated to be $1,000,000. The city will donate land appraised at $100,000 to accommodate the 50 electrified stalls. The city requests $500,000 in FY 2015 CMAQ funds. The private firm has committed to pay the remaining capital cost of the project. The city estimates that space utilization will be 90 percent and truck idling will be reduced by 8 hours per utilized space for a total of 360 hours reduced per annual average day.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $500,000.
- ***DIR*** = 360 hours of diesel vehicle idling reduced per annual average day.

Calculations:

$$\text{Daily Emissions Reduction} = 360 * (1.0 * \frac{9.17}{2} + (1.0 * .037)) * \frac{1}{1000} = 1.66 \frac{\text{kilograms}}{\text{day}}$$

$$\text{Capital Recovery Factor } (\mathbf{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\text{Cost-Effectiveness} = \frac{0.2184 * 500{,}000 * 1000}{1.66 * 365} = 180{,}228 \frac{\text{dollars}}{\text{metric ton}}$$

Auxiliary Power Units — EXAMPLE

A city located within the eight-hour ozone nonattainment area would like to install APUs equipped with 2003 Kubota engines on its fleet of diesel municipal buses. The city has 100 diesel buses that are all model year 2006 or older. Emissions will be reduced because the bus drivers will turn off their engines and receive compartment cooling during rest stops. The total cost of the project is estimated to be $700,000. The city requests $500,000 in FY 2015 CMAQ funds and estimates that bus idling will be reduced by 2 hours per bus per day for a total of 200 hours per annual average day.

The idle emission factors for the diesel buses before installing the APUs are 135 grams per hour for NOx and 3.68 grams per hour for PM-10 (FHWA, 2009). The 2003 Kubota engine has EPA-certified emissions levels of 4.7 grams per brake horsepower hour for NOx and 0.24 grams per brake horsepower per hour for PM-10 (40 CFR Part 89). Multiplying by a horsepower load factor of 5 (FHWA, 2009) produces APU emission rates of 23.5 grams per hour for NOx and 1.2 grams per hour for PM-10. These emissions are subtracted from the idling emissions for the buses without the APUs to obtain the net benefit of the APUs.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $500,000.
- ***DIR*** = 200 hours of diesel vehicle idling reduced per annual average day.

Calculations:

$$\textit{Daily Emissions Reduction} = 200 * (1.0 * \frac{(135-23.5)}{2} + (1.0 * (3.68-1.2)) * \frac{1}{1000} = 11.65 \ kg/day$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 500{,}000 * 1000}{11.65 * 365} = 25{,}681 \frac{dollars}{metric\ ton}$$

INTERSECTION IMPROVEMENTS

Intersection improvements include projects which add left or right turn lanes or construct roundabouts to improve traffic flow. These improvements reduce vehicle delay and idling emissions. The entity requesting CMAQ funds will provide the total reduction in vehicle hours of delay per weekday, based on traffic operations modeling of the intersection improvement. Industry standard intersection analysis tools such as Highway Capacity Manual (HCM) software, NETSIM, SYNCHRO, and TRANSYT-7F should be used to simulate the delay before and after the changes to the intersection (FHWA, 2009). MAG will apply idling emission factors to the vehicle hours of delay reduced to determine the daily emissions reduction. This methodology assumes that reductions in delay are the principal source of emissions benefits attributable to an intersection improvement.

MOVES will be run to estimate the idle emission factors for CO, TOG, NOx, and PM-10 for all vehicle classes in the year of project implementation ($\boldsymbol{IEF_{CO}}$, $\boldsymbol{IEF_{TOG}}$, $\boldsymbol{IEF_{NOx}}$, and $\boldsymbol{IEF_{PM}}$). The idle emission factor will be estimated by running the model at 2.5 miles per hour and converting the resulting emission factor in grams per mile to grams per hour, using 2.5 miles per hour.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- The total weekday vehicle hours of delay reduced due to the intersection improvement (***DR***).

Formulas:

$$Daily\ Emissions\ Reduction = DR * [\frac{w1*IEF_{CO}}{4} + \frac{w2*IEF_{TOG}}{2} + \frac{w3*IEF_{NOx}}{2} + w4*IEF_{PM}]*CF*\frac{1}{1000} = \frac{kilograms}{day}$$

where: ***DR*** = Reduction in total weekday vehicle hours of delay due to the improvement
IEF = the idling emission factor for all vehicle classes for each pollutant (in grams/hr)
CF = factor to convert from average weekday traffic (ADT) to annual average daily traffic (AADT); for freeways, multiply ADT by 0.92; for arterials, multiply ADT by 0.93.
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+i)^{life}\ (i)}{(1+i)^{life}\ -1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Additional Turning Lanes EXAMPLE

A city proposes to add second left turn lanes westbound and northbound and a dedicated right turn lane eastbound at an arterial intersection in 2015 at a cost of $2,000,000. The city proposes to pay $200,000 and requests $1,800,000 of CMAQ funding. A city consultant has simulated the traffic operations at the intersection before and after the capacity improvements using SYNCHRO and has determined that the total reduction in vehicle hours of delay will be 70 hours per average weekday in 2015.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $1,800,000.
- ***DR*** = 70 vehicle hours of delay reduced per weekday.

Calculations:

$$Daily\ Emissions\ Reduction\ =$$

$$70\ *\ \left(\frac{0.0*19.44}{4}+\frac{1.0*2.77}{2}+\frac{1.0*6.26}{2}+(1.0*0.93)\right)*0.93*\frac{1}{1000}=\ 0.35\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF})\ =\ \frac{(1+0.03)^{20}\ *\ (0.03)}{(1+0.03)^{20}\ -1}\ =\ 0.0672$$

$$Cost-Effectiveness\ =\ \frac{0.0672\ *\ 1{,}800{,}000\ *\ 1000}{0.35\ *\ 365}\ =\ 946{,}849\ \frac{dollars}{metric\ ton}$$

Roundabout EXAMPLE

ADOT proposes to build a roundabout in 2015 at a freeway interchange. Traffic operations modeling performed by an ADOT consultant indicates that the roundabout will reduce average vehicle delay by 120 hours per weekday. The cost of the project is $2,000,000. ADOT proposes to pay $200,000 and requests $1,800,000 of CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $1,800,000.
- ***DR*** = 120 vehicle hours of delay reduced per weekday.

Calculations:

$$Daily\ Emissions\ Reduction\ =$$

$$120\ *\ \left(\frac{0.0*19.44}{4}+\frac{1.0*2.77}{2}+\frac{1.0*6.26}{2}+(1.0*0.93)\right)*0.92*\frac{1}{1000}\ =\ 0.60\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF})\ =\ \frac{(1+0.03)^{20}\ *\ (0.03)}{(1+0.03)^{20}\ -1}\ =\ 0.0672$$

$$Cost-Effectiveness\ =\ \frac{0.0672\ *\ 1{,}800{,}000\ *\ 1000}{0.60\ *\ 365}\ =\ 552{,}329\ \frac{dollars}{metric\ ton}$$

NATURAL GAS AND ELECTRIC VEHICLES

The incremental cost of purchasing an alternative fuel vehicle versus a comparable gasoline fuel vehicle is eligible to be funded with CMAQ (FHWA, 2011). Natural gas vehicles produce lower exhaust emissions than gasoline-fueled vehicles, while electric vehicles produce zero exhaust emissions. The CMAQ methodology for quantifying the emission reductions and cost-effectiveness of natural gas vehicles, as a potential candidate for CMAQ funding, relies on a comparison of natural gas and gasoline exhaust emission factors for the same vehicle type (e.g., light duty auto). Electric vehicles are assumed to eliminate the exhaust emissions for the type and model year of gasoline vehicles being replaced. MOVES2010a emission factors will be used to evaluate the emission reductions and cost-effectiveness of electric vehicles. Since MOVES2010a does not currently provide emission factors for natural gas vehicles, MOBILE6.2 emission factors will be used to compare the emissions produced by natural gas and gasoline vehicles. If a future version of MOVES provides emission factors for natural gas and other alternative fuel vehicles, MOVES will be used to evaluate these proposed CMAQ projects.

For electric vehicles, the MOVES model will be run for the model year of the gasoline vehicle to be replaced to estimate the onroad exhaust emission factors for CO, TOG, NOx, and PM-10. These emission factors will be multiplied by the daily vehicle miles of travel to determine the emissions reduced in grams per day for each electric vehicle that is purchased.

For natural gas vehicles, the MOBILE6.2 model will be run to estimate the onroad exhaust emission factors for CO, VOC, NOx, and PM-10 for the natural gas vehicle in the model year to be purchased and the gasoline vehicle in the model year to be replaced. For natural gas vehicles, the exhaust emission factors for volatile organic compounds (VOC) will be substituted for total organic gases (TOG) in the equations below, because the VOC component of TOG emissions is the major contributor to the formation of ground-level ozone and more accurately represents the ozone reduction benefits of natural gas vehicles. The exhaust emission factor for the natural gas vehicle will be subtracted from the emission factor for the gasoline vehicle to be replaced. The difference will be multiplied by the daily vehicle miles of travel to determine the emissions reduced in grams per day for each natural gas vehicle that is purchased.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** (difference between cost of alternative vehicle and comparable gasoline vehicle)**.**
- Number of vehicles by fuel type (e.g., electric or natural gas) and vehicle type (e.g., car) (***N***).
- Average number of miles traveled per weekday by vehicle being replaced ***(VMT)***.
- Model year and type of gasoline vehicle(s) being replaced.

Formulas:

$$GVE = \left[\frac{w1*ONF_{CO}}{4}+\frac{w2*ONF_{TOG}}{2}+\frac{w3*ONF_{NOx}}{2}+w4*ONF_{PM}\right]*\frac{250}{365} = \frac{grams}{day}$$

$$AVE = \left[\frac{w1*ONF_{CO}}{4}+\frac{w2*ONF_{TOG}}{2}+\frac{w3*ONF_{NOx}}{2}+w4*ONF_{PM}\right]*\frac{250}{365} = \frac{grams}{day}$$

where: ***GVE* =** Emissions for the type and model year of gasoline vehicle being replaced
AVE* =** Emissions for the alternative vehicle (for electric vehicles, ***AVE = zero)
ONF = the vehicle exhaust emission factor for each pollutant
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

$$Daily\ Emissions\ Reduction = N * (GVE-AVE) * VMT * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***N* =** Number of gasoline vehicles being replaced
***VMT* =** Average weekday miles to be traveled by each new vehicle
ONF = the onroad light duty vehicle emission factor for each pollutant

$$Capital\ Recovery\ Factor\ (CRF) = \frac{(1+i)^{life}\ (i)}{(1+i)^{life}\ -1}$$

where: ***i*** = discount rate of 3 percent
life = vehicle life, based on the difference between the model year of vehicle being purchased and the model year being replaced

$$Cost-Effectiveness = \frac{CRF * \underline{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the difference between the cost of the alternative vehicle and a comparable gasoline vehicle

Natural Gas Vehicles — EXAMPLE

A city requests FY 2015 CMAQ funds to replace a 2007 eight-passenger gasoline-fueled van with a 2015 eight-passenger natural gas-fueled van. The city provides documentation that a comparable 2015 model year gasoline van would cost $5,000 less than the natural gas van. The city will provide an additional $30,000 in local funds to pay for the new natural gas van. The city estimates that the gasoline van being replaced travels 50 miles on a typical weekday. Since a natural gas vehicle is being requested, MOBILE6.2 will be utilized to estimate the exhaust emission factors. The estimated life of the van is 8 years (2015 model year minus 2007 model year).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $5,000.
- ***N*** = 1 natural gas van.
- ***VMT*** = 50 miles per weekday.
- ***life*** = 8 years.

Calculations:

$$\boldsymbol{GVE} = [\frac{0.0*3.6367}{4}+\frac{1.0*0.0915}{2}+\frac{1.0*0.2658}{2}+1.0*0.0042]*\frac{250}{365} = 0.1252\ \frac{grams}{day}$$

$$\boldsymbol{AVE} = [\frac{0.0*0.4800}{4}+\frac{1.0*0.0030}{2}+\frac{1.0*0.3283}{2}+1.0*0.0042]*\frac{250}{365} = 0.1163\ \frac{grams}{day}$$

$$Daily\ Emissions\ Reduction = 1 * (0.1252 - 0.1163) * 50 * \frac{1}{1000} = 0.0004\ kg/day$$

$$\boldsymbol{CRF} = \frac{(1+0.03)^8 * (0.03)}{(1+0.03)^8 - 1} = 0.1425$$

$$Cost\text{-}Effectiveness = \frac{0.1425 * 5{,}000 * 1{,}000}{0.0004 * 365} = 4{,}880{,}137\ \frac{dollars}{metric\ ton}$$

Electric Vehicles — EXAMPLE

A city requests FY 2015 CMAQ funds to purchase a 2015 electric vehicle to replace a 2010 gasoline-fueled car used by city staff. The city provides documentation that a comparable 2015 gasoline car would cost $10,000 less than the electric car. The city will provide an additional $20,000 in local funds to purchase the electric vehicle. The city estimates that the gasoline car being replaced travels 50 miles on a typical weekday. Since an electric vehicle is being requested, MOVES2010a will be utilized to estimate the exhaust emission factors for the 2010 model year car, while the electric vehicle will be assumed to generate zero emissions. The estimated life of the vehicle is 5 years (2015 model year minus 2010 model year).

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $10,000.
- ***N*** = 1 electric vehicle.
- ***VMT*** = 50 miles.
- ***life*** = 5 years.

Calculations:

$$\boldsymbol{GVE} = [\frac{0.0*1.1273}{4}+\frac{1.0*0.0152}{2}+\frac{1.0*0.0719}{2}+1.0*0.0030]*\frac{250}{365} = 0.0319\ \frac{grams}{day}$$

$$\boldsymbol{AVE} = 0.0000\ \frac{grams}{day}$$

$$Daily\ Emissions\ Reduction = 1 * (0.0319 - 0.0000) * 50 * \frac{1}{1000} = 0.0016\ kg/day$$

$$\boldsymbol{CRF} = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$Cost\text{-}Effectiveness = \frac{0.2184 * 10{,}000 * 1{,}000}{0.0016 * 365} = 3{,}739{,}726\ \frac{dollars}{metric\ ton}$$

PARK AND RIDE FACILITIES

"Park and Ride Lots" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. Park and ride facilities reduce vehicle trips and emissions by encouraging carpooling, vanpooling, and transit ridership. These projects reduce light duty vehicle exhaust emissions of CO, TOG, and NOx, and exhaust plus reentrained emissions of PM-10.

The methodology is based on the number of park and ride spaces to be built and the projected utilization rate when the facility is scheduled to open. It is assumed that each vehicle parked in the facility (spaces times the utilization rate) represents two commute trips. The average trip length for commute trips is derived from regional commuting data collected by the Maricopa County Trip Reduction Program. The average trip length driven to park and ride lots (derived from a MAG park-and-ride lot survey) is subtracted from the average commute trip length. The net trip length is applied to the total commute trips reduced to obtain the average weekday reduction in vehicle miles of travel (VMT).

The MOVES model will be run for the project implementation year to estimate the onroad light duty vehicle emission factors (Road Types 2-5) for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, *and* ONF_{PM}). The paved road emission factor for all roads (0.26 grams per mile) will be added to ONF_{PM}. These emission factors will be multiplied by the reduction in vehicle miles of travel.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost.***
- Number of spaces ***(S)***.
- Estimated utilization rate ***(U)***.

Formulas:

$$\textit{VMT Reduced } (\boldsymbol{VMTR}) = \boldsymbol{S} * \boldsymbol{U} * \mathbf{2} * (\mathbf{15.4} - \mathbf{3.5})$$

where: ***S*** = number of parking spaces provided in the park and ride facility
U = average weekday utilization rate
2 = number of vehicle commute trips per average weekday
15.4=average commute trip length by all modes (MCAQD, 2009)
3.5 =average miles driven to park and ride lots

$$\boldsymbol{VER} = \boldsymbol{VMTR} * \left(\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF)\right) * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***ONF*** = the onroad light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)
250/365 = factor to convert from a weekday to an annual average day
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}} - 1}$$

where: $\boldsymbol{i}$ = discount rate of 3 percent
life = effectiveness period of 20 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{\boldsymbol{VER} * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Park and Ride Lot **EXAMPLE**

A city requests $200,000 in CMAQ funds to construct a park and ride lot with 300 spaces in 2015. The city will use an additional $50,000 in local funds. The city estimates that 90 percent of these spaces will be utilized on a typical weekday.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $200,000.
- ***S*** = 300 spaces.
- ***U*** = 90% utilization.

Calculations:

$$VMT\ Reduced\ (\boldsymbol{VMTR}) = 300 * 0.90 * 2 * 11.9 = 6{,}426$$

$$\boldsymbol{VER} = 6{,}426 * \left(\frac{0.0*2.00}{4} + \frac{1.0*0.12}{2} + \frac{1.0*0.41}{2} + (1.0*(0.04+0.26))\right) * \frac{1}{1000} * \frac{250}{365} = 2.49\ \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$Cost\text{-}Effectiveness = \frac{0.0672 * 200{,}000 * 1000}{2.49 * 365} = 14{,}788\ \frac{dollars}{metric\ ton}$$

PAVING PROJECTS

"Reduce Particulate Emissions from Unpaved Roads and Alleys," "Curbing, Paving or Stabilizing Shoulders on Paved Roads," and "Paving, Vegetating and Chemically Stabilizing Unpaved Access Points Onto Paved Roads" are committed measures in the MAG Serious Area PM-10 Plan (MAG, 2000a). Paving projects are effective in reducing PM-10 and therefore, represent potential candidates for CMAQ funds. Typical projects requesting CMAQ funds are for paving unpaved shoulders, curbs and gutters, unpaved roads, unpaved alleys, and unpaved access points. These projects reduce PM-10, but not CO, TOG, or NOx.

The emission factor (*BEF*) for unpaved roads, based on the Maricopa County 2008 Periodic Emissions Inventory, is 660.16 grams per mile (MCAQD, 2010). The paved road emission factor (*AEF*) on low volume arterials (<10,000 vehicles per day) with unpaved shoulders is 1.47 grams per mile. The difference between the unpaved and paved emission rate (658.69 g/mi) represents the reduction in PM-10 emissions due to paving dirt roads in the PM-10 nonattainment area.

The unpaved alley emission rate is 417.45 grams per mile (MCAQD, 2010). The difference between the unpaved and paved (i.e., 1.47) emission rates, 415.98 grams per mile, represents the emission reduction for paving dirt alleys in the PM-10 nonattainment area.

The benefits of paving unpaved shoulders and/or installing curbs and gutters (C&G) are derived from the MAG Silt Loading Study (MAG, 2007c) and the new AP-42 paved road PM-10 equation (EPA, 2011). As shown below, the reduction factors (RFs) for paving shoulders vary based on the extent of shoulder and/or C&G paving. Shoulder paving projects within the Salt River Area receive higher reduction benefits. The Salt River Area is bounded by Van Buren Street on the north, 7th Street on the east, Baseline Road on the south, and 59th Avenue on the west.

To be consistent with the Serious Area PM-10 Plan (MAG, 2000a), paving of unpaved access points is assumed to reduce emissions by 343 grams per access point per day. No credit for access points will be assigned if there are no access points identified on the CMAQ project application.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Project length (*in centerline miles*).
- Average weekday traffic (***ADT)*** for paving unpaved roads, alleys or shoulders.
- The number of access points to be paved (*access points*), if paving unpaved access points.
- Whether the project includes paving the shoulder and/or providing curb and gutter on one or both sides of the road.
- If the project is located within four miles of a PM-10 monitor, specify which monitor.

Formulas:

For Paving Unpaved Shoulders and/or Providing Curb and Gutter (C&G):

$$\textit{Daily Emissions Reduction} = w4 * RF * \textbf{\textit{miles}} * \textbf{\textit{ADT}} * 0.93 * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***RF*** = Reduction factor:

For low volume roads (<10,000 ADT) =

0.76 g/mi, if paving shoulders and providing C&G on both sides of the road;
0.57 g/mi, if paving shoulders on both sides of the road without C&G;
0.38 g/mi, if paving shoulder and providing C&G on one side of the road;
0.29 g/mi, if paving shoulder on one side of the road without C&G;
0.19 g/mi, if providing C&G on both sides of a road with paved shoulders; or
0.10 g/mi, if providing C&G on one side of a road with a paved shoulder.

For high volume roads ($\geq$ 10,000 ADT) =

0.53 g/vmt, if paving shoulders and providing C&G on both sides of the road;
0.40 g/mvt, if paving shoulders on both sides of the road without C&G;
0.27 g/vmt, if paving shoulder and providing C&G on one side of the road;
0.20 g/vmt, if paving shoulder on one side of the road without C&G;
0.14 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.07 g/vmt, if providing C&G on one side of a road with a paved shoulder.

For all roads inside the Salt River Area =

1.31 g/vmt, if paving shoulders and providing C&G on both sides of the road;
0.98 g/mvt, if paving shoulders on both sides of the road without C&G;
0.66 g/vmt, if paving shoulder and providing C&G on one side of the road;
0.49 g/vmt, if paving shoulder on one side of the road without C&G;
0.32 g/vmt, if providing C&G on both sides of a road with paved shoulders; or
0.16 g/vmt, if providing C&G on one side of a road with a paved shoulder.

miles = the length of the project (in centerline miles)
ADT = the average weekday traffic on the road adjacent to the unpaved shoulders
0.93 = the factor to convert from weekday to annual average daily traffic on arterials.
w4 = the PM-10 weighting factor (***w4*** = 2, if the project is within 4 miles of a PM-10 monitor; otherwise, ***w4*** = 1)

For Paving Unpaved Roads or Alleys:

$$Daily\ Emissions\ Reduction = \boldsymbol{w4} * (\boldsymbol{BEF} - \boldsymbol{AEF}) * \boldsymbol{miles} * \boldsymbol{ADT} * 0.93 * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***BEF*** = the PM-10 emission factor for vehicles traveling on unpaved roads or alleys
AEF = the PM-10 emission factor for vehicles traveling on paved roads or alleys with unpaved shoulders (1.47 g/mi)
miles = the length of the project (in centerline miles)
ADT = the average weekday traffic on the unpaved road or alley
0.93 = the factor to convert from weekday to annual average daily traffic on arterials.
w4 = the PM-10 weighting factor (***w4*** = 2, if the project is within 4 miles of a PM-10 monitors; otherwise, ***w4*** = 1)

For Paving Unpaved Access Points:

$$\textit{Daily Emissions Reduction} = \boldsymbol{w4} * \frac{343 \textit{ grams}}{\textit{access point-day}} * \textbf{\textit{access points}} * \frac{1}{1000} = \frac{\textit{kilograms}}{\textit{day}}$$

where: ***access points*** = the number of access points to be paved
w4 = the PM-10 weighting factor ***(w4*** = 2, if the project is within 4 miles of a PM-10 monitor; otherwise, ***w4*** = 1)

For All Paving Projects:

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}} - 1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 20 years

$$\textit{Cost-Effectiveness} = \frac{\boldsymbol{CRF} * \textbf{\textit{CMAQ Cost}} * 1000}{\textit{Daily Emissions Reduction} * 365} = \frac{\textit{dollars}}{\textit{metric ton}}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Paving Unpaved Roads Without Paved Shoulders **EXAMPLE**

A jurisdiction proposes to pave a 1.5 mile section of unpaved road in 2015 which has an average weekday traffic volume of 120 vehicles per day. No paved shoulders or curb and gutter will be provided. The project application does not specify how many access points will be paved. The project is located within four miles of a PM-10 monitor. The total cost of the project is $675,000. The jurisdiction proposes to pay $75,000 and requests $600,000 in CMAQ funds.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $600,000.
- Project length (***miles***) = 1.5 miles.
- Average weekday traffic (***ADT***) on the unpaved road = 120.
- No access points are being paved.
- The project is located within four miles of a PM-10 monitor.

Calculations:

$$\textit{Daily Emissions Reduction} = 2.0 * 658.69 * 1.5 * 120 * 0.93 * \frac{1}{1000} = 220.53\ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 600{,}000 * 1000}{220.53 * 365} = 501\ \frac{\textit{dollars}}{\textit{metric ton}}$$

Paving Unpaved Roads, Shoulders and Curb and Gutter EXAMPLE

A city proposes to pave one mile of an unpaved road in 2015 which has a traffic volume of 120 vehicles per average weekday. The project will also pave the shoulders and provide curb and gutter on both sides of the road. The paving project is not located within four miles of a PM-10 monitor. The project application indicates that four access points will be paved. The total cost of the project is $675,000. The city proposes to pay $75,000 and requests $600,000 of CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $600,000.
- Project length (***miles***) = 1 mile.
- Average weekday traffic (***ADT***) on unpaved road = 120.
- Access points being paved = 4.
- The project is not located within four miles of any PM-10 monitor.

Calculations:

Calculate the daily emissions reduction from paving the unpaved road:

$$\textit{Daily Emissions Reduction} = 1.0 * 658.69 * 1.0 * 120 * 0.93 * \frac{1}{1000} = 73.51\ \frac{\textit{kilograms}}{\textit{day}}$$

Calculate the daily emissions reduction from paving the shoulder and providing curb and gutter on both sides of the road:

$$\textit{Daily Emissions Reduction} = 1.0 * 0.76 * 1.0 * 120 * 0.93 * \frac{1}{1000} = 0.08\ \frac{\textit{kilograms}}{\textit{day}}$$

Calculate the daily emissions reduction from paving four unpaved access points:

$$\textit{Daily Emissions Reduction} = 1.0 * 343 * 4 * \frac{1}{1000} = 1.37 \frac{\textit{kilograms}}{\textit{day}}$$

The total daily emissions reduction from paving the unpaved road with a shoulder and curb and gutter and paving four unpaved access points:

$$\textit{Total Daily Emissions Reduction} = 73.51 + 0.08 + 1.37 = 74.96 \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^{20} * (0.03)}{(1+0.03)^{20} - 1} = 0.0672$$

$$\textit{Cost-Effectiveness} = \frac{0.0672 * 600{,}000 * 1000}{74.96 * 365} = 1{,}474 \frac{\textit{dollars}}{\textit{metric ton}}$$

PM-10 CERTIFIED STREET SWEEPERS

"PM-10 Efficient Street Sweepers" is a committed measure in the Serious Area PM-10 Plan (MAG, 2000a). Street sweepers certified in accordance with South Coast Air Quality Management District Rule 1186 reduce PM-10 on paved roads, which reduces reentrainment of PM-10 by vehicles traveling on the road. Therefore, the purchase of PM-10 certified street sweepers is eligible for CMAQ funds. Emission reductions for this type of project will be calculated for PM-10 only.

The emission reductions are addressed as two separate components: the reduction in reentrained dust from vehicles traveling on the roadways cleaned by the sweeper and the reduction in dust from the actual sweeping process. These components will be combined to determine the total emissions reduction associated with a PM-10 certified street sweeper. Each component is described in a separate section below.

Reduced Reentrained Dust from Vehicles Traveling on Roadways. If the sweeper is being purchased to replace an existing conventional sweeper, the emission reduction will be based on a comparison of the emissions from the base silt loading on a paved road after using a conventional sweeper versus emissions from the reduced silt loading attributable to a PM-10 certified sweeper. The reduced silt loading results in lower emissions of reentrained dust from vehicles traveling on the road. If the sweeper is being purchased to replace an older PM-10 certified sweeper, the emission reduction will be based on a comparison of the utilization rates of the new PM-10 certified sweeper versus the older certified sweeper.

If the street sweeper is being purchased to increase the frequency of sweeping, the emission reduction will be based on a comparison of emissions using a PM-10 certified sweeper with the new cycle length (***daysnew***) versus the same sweeper with the existing cycle length (***days***). If the street sweeper is being purchased to expand coverage, the emission reduction will be based on the difference between the emissions from an unswept road (using the initial emission factors in Tables 4 and 5) and the emissions after sweeping with a PM-10 certified unit for the expanded area (***milesnew***).

The emission factor for reentrained dust varies depending upon how often a street is swept. It will be assumed that requested PM-10 certified street sweepers use the same sweeping schedule as the conventional street sweepers they replace. It will also be assumed that the silt loading on a street returns to its initial level nine days after the street is swept by a PM-10 certified sweeper and six days after being swept by a conventional sweeper. The unswept emission factors based on the new AP-42 equation for paved roads are 0.11 grams per mile for freeways and 0.35 grams per mile for arterials outside the Salt River Area. The latter represents a 2011 VMT-weighted average of the low and high ADT emission factors for all arterials in the PM-10 nonattainment area.

In the Salt River Area, Sierra Research recommends a paved road PM-10 emission factor of 3.44 grams per mile for all arterials (MAG, 2008). The Salt River Area is defined as the area bounded by Van Buren Street on the north, 7th Street on the east, Baseline Road on the south, and 59th Avenue on the west. The 3.44 g/mi emission factor has been reduced by 62 percent to represent the percent reduction in the arterial emission factor using the 2011 AP-42 equation (i.e., 0.35 grams per mile) versus the 2006 AP-42 equation (i.e., 0.92 grams per mile). The resulting paved road emission rate of 1.31 grams per mile is higher in the Salt River Area due to the heavier weight (i.e., 4.1 tons) of vehicles traveling on paved roads in this industrial area, compared with the average vehicle weight of 2.72 tons for vehicles traveling on arterials in the nonattainment area. Emission reduction credit for PM-10 certified street sweepers to be used in the Salt River Area will be calculated using this higher paved road emission factor.

The PM-10 certified sweepers are assumed to reduce the initial silt loading by 86 percent (i.e. the silt loading is reduced to 14 percent of the initial level), while conventional sweepers reduce the initial silt loading by 55 percent. The schedule for the percent of initial silt loading on days after PM-10 certified street sweeping is as follows: day of sweeping - 14 percent, 1 day after - 24 percent, 2 days after - 34 percent, 3 days after - 44 percent, 4 days after - 54 percent, 5 days after - 64 percent, 6 days after - 74 percent, 7 days after - 84 percent, 8 days after - 94 percent, and nine days or more after - 100 percent of initial silt loading. Similarly, the silt loading at varying days after sweeping with a conventional sweeper is as follows: day of sweeping - 45 percent, 1 day after - 55 percent, 2 days after - 65 percent, 3 days after - 75 percent, 4 days after - 85 percent, 5 days after - 95 percent, and 6 days or more after - 100 percent of initial silt loading.

The PM-10 emission factors for sweeping freeways and non-freeways with a PM-10 certified unit are listed in Table 3 for various days following street sweeping. Similar factors for a conventional sweeper are provided in Table 4. In Tables 3 and 4, the emission factors for sweeping non-freeways in the Salt River Area are based on a higher initial unswept emission factor of 3.44 grams per mile recommended by Sierra Research (MAG, 2008). For the 2011 CMAQ methodologies, this emission factor has been reduced by 62 percent, which is the change in the average arterial paved road emission rate (from 0.92 g/mi to 0.35 g/mi) due to the new AP-42 equation (EPA, 2011).

Based on sweeping frequency, the emission factors in Tables 3 and 4 will be combined to create a weighted average emission factor as shown in the formulas below. Separate weighted emission factors will be estimated to reflect the impact of sweeping with PM-10 certified sweepers and conventional sweepers. The difference between these two emission factors is the incremental reduction in emissions achieved by replacing a conventional street sweeper with a PM-10 certified unit.

The difference between the initial unswept emission factor and the PM-10 certified sweeper emission factor when applied to the new area being swept (***milesnew***) represents the reduction in emissions achieved by expanding the area of sweeping. The difference between the PM-10 certified emission factors for the old (***days***) and new (***daysnew***) cycle lengths represents the reduction achieved by increasing the frequency of sweeping.

To calculate the benefits of a new PM-10 certified sweeper that will replace an older PM-10 certified unit, the utilization rate of the new and older sweepers will be compared. The project applicant will provide the percent of time that the older unit was not utilized during the previous year due to maintenance and repair downtime. The average daily benefit of the new sweeper based on the emission factors in Table 3 will be reduced by the difference between 95 percent (the assumed utilization rate for a new sweeper) and the utilization rate (1.0 - percent downtime) for the older sweeper.

Reduced Emissions During the Sweeping Process. The reduction in PM-10 from the actual sweeping process will be based upon the California Air Resources Board estimate that a PM-10 certified street sweeper entrains 0.05 pounds per mile less PM-10 than a conventional sweeper during the sweeping process (CARB, 2005). For this analysis, the emissions reduction is converted to kilograms per vehicle mile, resulting in an emission reduction factor of 0.023 kilograms per vehicle mile traveled by the PM-10 certified sweeper. This estimate will be combined with the estimate of miles traveled per day by the PM-10 certified sweeper to produce a total reduction in emissions in kilograms for an average day. This reduction will only be applied when a PM-10 certified sweeper will replace a conventional sweeper.

PM-10 certified street sweepers are eligible for purchase with CMAQ funds if they replace an existing unit that has not been certified by South Coast Rule 1186, replace a Rule 1186 certified unit that is at least eight years old, increase the frequency of sweeping, expand the area that is swept, or a combination of these functions. Input requirements for each of these functions are described below. If the requested unit will perform more than one function, the requestor will need to provide all of the inputs described under each function. Note that the sweeping cycle (***days*** or ***daysnew***) referred to below represents the number of calendar days that elapse before the same lane of road is re-swept by the same sweeper.

Table 3. PM_{10} Emission Factors as a Function of Days After Sweeping with a PM_{10} Certified Sweeper

	Freeway	Non-freeway	Salt River Area Non-freeway
Day of sweeping (k=1)	0.03 g/vmt	0.10 g/vmt	0.36 g/vmt
1 day after sweeping (k=2)	0.04 g/vmt	0.14 g/vmt	0.52 g/vmt
2 days after sweeping (k=3)	0.05 g/vmt	0.17 g/vmt	0.65 g/vmt
3 days after sweeping (k=4)	0.06 g/vmt	0.21 g/vmt	0.77 g/vmt
4 days after sweeping (k=5)	0.07 g/vmt	0.23 g/vmt	0.88 g/vmt
5 days after sweeping (k=6)	0.08 g/vmt	0.26 g/vmt	0.98 g/vmt
6 days after sweeping (k=7)	0.09 g/vmt	0.29 g/vmt	1.07 g/vmt
7 days after sweeping (k=8)	0.10 g/vmt	0.31 g/vmt	1.17 g/vmt
8 days after sweeping (k=9)	0.11 g/vmt	0.34 g/vmt	1.26 g/vmt
9 days after sweeping (k>9)	0.11 g/vmt	0.35 g/vmt	1.31 g/vmt

Table 4. PM_{10} Emission Factors as a Function of Days After Sweeping with a Conventional Sweeper

	Freeway	Non-freeway	Salt River Area Non-freeway
Day of sweeping (k=1)	0.07 g/vmt	0.21 g/vmt	0.78 g/vmt
1 day after sweeping (k=2)	0.07 g/vmt	0.24 g/vmt	0.89 g/vmt
2 days after sweeping (k=3)	0.08 g/vmt	0.26 g/vmt	0.99 g/vmt
3 days after sweeping (k=4)	0.09 g/vmt	0.29 g/vmt	1.08 g/vmt
4 days after sweeping (k=5)	0.10 g/vmt	0.31 g/vmt	1.18 g/vmt
5 days after sweeping (k=6)	0.11 g/vmt	0.34 g/vmt	1.26 g/vmt
6 days after sweeping (k>6)	0.11 g/vmt	0.35 g/vmt	1.31 g/vmt

Inputs Required from Entity Requesting CMAQ Funds:

For all sweeper requests:

- ***CMAQ Cost***.
- Average weekday traffic (***ADT***) per lane on streets to be swept by the PM-10 certified sweeper.
- Whether the requested unit will sweep freeways or non-freeways.
- Whether the sweeper will be used in the Salt River Area.
- If the sweeping will occur within 4 miles of a PM-10 monitor, specify which monitor.

If the new sweeper will replace a non-certified sweeper:

- Current number of days per sweeping cycle (***days***) for the unit being replaced.
- Lane miles (***miles***) swept per cycle by the unit being replaced.

If the new sweeper will replace an older PM-10 certified sweeper:

- Percent of time the older certified sweeper was not utilized during the previous year as a result of maintenance and repair downtime.
- Current number of days per sweeping cycle (***days***) for the unit being replaced.
- Lane miles (***miles***) swept per cycle by the unit being replaced.

If the new sweeper will be used to increase the frequency of sweeping:

- Planned number of days per sweeping cycle (***daysnew***) for the lanes to be swept.
- Current number of days per sweeping cycle (***days***) for the lanes to be swept.
- Lane miles (***miles***) of roads to be swept per cycle.

If the new sweeper will be used to expand the area to be swept:

- Planned number of days per cycle (***daysnew***) on roads in the expanded area.
- Lane miles (***milesnew***) of roads to be swept per cycle in the expanded area.

Formulas:

Reduced Reentrained Dust from Vehicles Traveling on Roadways:

Emission factor for roads swept with PM-10 certified street sweepers:

$$PM\text{-}10\ \mathit{Certified\ Sweeper\ Emission\ Factor}\ (\boldsymbol{PEF}) = \frac{\sum_{k=1}^{\boldsymbol{days}} (PM\text{-}10\ \mathit{certified\ emission\ factor})_k}{\boldsymbol{days}}$$

Emission factor for roads swept with conventional street sweepers:

$$Conventional\ Sweeper\ Emission\ Factor\ (\boldsymbol{CEF}) = \frac{\sum_{k=1}^{\boldsymbol{days}} (conventional\ emission\ factor)_k}{\boldsymbol{days}}$$

where: (***PM-10 certified emission factor***)$_k$ = the emission factor on day k from Table 3
(***conventional emission factor***)$_k$ = the emission factor on day k from Table 4
days = current number of days per sweeping cycle

Replacing a Conventional Sweeper:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{miles} * \boldsymbol{AADT} * (\boldsymbol{CEF} - \boldsymbol{PEF}) * \frac{1}{1000} = \frac{kilograms}{day}$$

Replacing an Older PM-10 Certified Sweeper:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{miles} * \boldsymbol{AADT} * \boldsymbol{PEF} * (0.95 - URATE_{old}) * \frac{1}{1000} = \frac{kilograms}{day}$$

Increasing the Frequency of Sweeping:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{miles} * \boldsymbol{AADT} * (\boldsymbol{PEF} - \boldsymbol{PEF_{new}}) * \frac{1}{1000} = \frac{kilograms}{day}$$

Expanding the Coverage of Sweeping:

$$Daily\ Emissions\ Reduction = w4 * \boldsymbol{milesnew} * \boldsymbol{AADT} * (\boldsymbol{IEF} - \boldsymbol{PEF_{new}}) * \frac{1}{1000} = \frac{kilograms}{day}$$

where: ***w4*** = the PM-10 weighting factor (***w4*** = 2, if the sweeping will occur within 4 miles of a PM-10 monitor; otherwise, ***w4*** = 1)
miles = lane miles of street to be swept per cycle
AADT = annual average daily traffic per through lane to be swept by the requested sweeper (for freeways, multiply 0.92 by the average weekday traffic (ADT); for arterials, multiply 0.93 by the ADT).

$URATE_{old}$ = percent utilization of the older PM-10 certified sweeper during the past year
PEF_{new} = PM-10 certified sweeper emission factor calculated with ***days*** = ***daysnew***
IEF = the initial silt loading emission factor in Table 3 (i.e., 9 days after sweeping) or Table 4 (i.e., 6 days after sweeping)
milesnew = lane miles of streets to be swept per cycle in the expanded area

Reduced Emissions During the Sweeping Process (This reduction is only applied if the requested sweeper replaces a non-certified unit):

$$\text{Daily Emissions Reduction for the Sweeping Process} = w4 * \left(\frac{\textbf{miles}}{\textbf{days}}\right) * 0.023 = \frac{kilograms}{day}$$

where: **0.023** = kilograms per vehicle mile reduction in reentrained dust from the sweeping process itself.
w4 = the PM-10 weighting factor

$$\text{Capital Recovery Factor } (\textbf{CRF}) = \frac{(1+i)^{\textbf{life}}\ (i)}{(1+i)^{\textbf{life}}\ -1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 8 years (MAG, 1998)

$$\text{Cost-Effectiveness} = \frac{\textbf{CRF} * \textbf{CMAQ Cost} * 1000}{\text{Daily Emissions Reduction} * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

PM-10 Certified Street Sweepers — EXAMPLE

A city proposes to purchase a PM-10 certified street sweeper in 2015 to replace a non-certified sweeper. The replacement unit will not be used to increase the frequency of sweeping or the area swept. The cost of CMAQ-eligible equipment on the sweeper is $150,000. The city proposes to pay $15,000 and requests $135,000 of CMAQ funding. The certified sweeper will be used on streets (non-freeways) outside the Salt River Area with average weekday traffic per through lane of 5,000 vehicles. Each lane mile of street is currently swept once every 14 days. During this 14-day cycle, 200 lane miles are swept using the non-certified sweeper being replaced. The sweeping with the PM-10 certified unit will occur within four miles of a PM-10 monitor.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $135,000.
- Average weekday traffic per through lane swept with the conventional sweeper to be replaced (***ADT***)= 5,000 vehicles/day.
- Current number of days in the sweeping cycle using the conventional sweeper to be replaced (***days***) = 14 days.
- Lane miles of streets swept per sweeping cycle with the conventional sweeper to be replaced (***miles***) = 200 lane miles.
- The sweeping will occur outside the Salt River Area, but within 4 miles of a PM-10 monitor.

Calculations:

$$\boldsymbol{CEF} = \frac{0.21 + 0.24 + 0.26 + 0.29 + 0.31 + 0.34 + (8 * 0.35)}{14} = 0.318$$

$$\boldsymbol{PEF} = \frac{0.10 + 0.14 + 0.17 + 0.21 + 0.23 + 0.26 + 0.29 + 0.31 + 0.34 + (5 * 0.35)}{14} = 0.271$$

$$\textit{Daily Emissions Reduction for Reentrainment} = 2 * 200 * (5{,}000 * 0.93) * (0.318 - 0.271) * \frac{1}{1000} = 87.42 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Daily Emissions Reduction for the Sweeping Process} = 2 * \frac{200}{14} * 0.023 = 0.66 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Total Daily Emissions Reduction} = 87.42 + 0.66 = 88.08 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\boldsymbol{CRF} = \frac{(1+0.03)^{8} * (0.03)}{(1+0.03)^{8} - 1} = 0.1425$$

$$\textit{Cost-Effectiveness} = \frac{0.1425 * 135{,}000 * 1000}{88.08 * 365} = 598 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

RIDESHARE PROGRAMS

“Employer Rideshare Program Incentives” and “Preferential Parking for Carpools and Vanpools” are committed control measures in the MAG 1999 Serious Area CO and PM-10 Plans. Ridesharing in carpools and vanpools reduces emissions by decreasing the total vehicle miles of travel (VMT) for commute trips. MAG programs CMAQ funding for the Regional Rideshare Program operated by RPTA and partial funding for the Capitol Rideshare Program conducted by the Arizona

Department of Administration. The Ozone Education Program and the Telework Program, both of which were previously evaluated as separate CMAQ-funded projects, have been integrated into the Regional Rideshare Program.

Based on the TDM survey conducted in 2009 (Valley Metro, 2010), an average of 11 percent of all work trips are made by carpools and vanpools. The average trip length of commute trips by all modes in 2009 was 15.4 miles (MCAQD, 2009) and the average vehicle occupancy was 1.28 (Cummings, 2010).

The MOVES model will be run for the CMAQ funding year to estimate the onroad (Road Types 2-5) light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, *and* ONF_{PM}). The paved road emission factor for all roads of 0.26 grams per mile will be added to ONF_{PM}. MOVES will also be run to generate off-network (Road Type 1) light duty vehicle emission factors for each pollutant (OFF_{CO}, OFF_{TOG}, OFF_{NOx}, *and* OFF_{PM})[14]. The onroad emission factors will be multiplied by vehicle miles of travel, while the off-network emission factors will be multiplied by the vehicles reduced. These emission reductions will be summed to estimate the total benefit of the Rideshare Program.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Percent of carpooling participation attributable to the Regional Rideshare Program (***P***).

Formulas:

$$VMT\ Reduced\ (\boldsymbol{VMTR}) = \frac{\mathbf{0.11} * \boldsymbol{W} * \boldsymbol{P}}{\mathbf{1.28}} * \mathbf{15.4}$$

$$Vehicles\ Reduced\ (\boldsymbol{VR}) = \frac{\boldsymbol{VMTR}}{\mathbf{15.4} * \mathbf{1.6}}$$

where: **0.11** = percent of total commute trips by carpooling and vanpooling (Valley Metro, 2010)
W = daily home-based work person trips = **1.6** * total employment in Maricopa County for CMAQ funding request year (MAG trip attraction equation)
P = percent of carpooling attributable to the Regional Rideshare Program
1.28 = average vehicle occupancy for all modes (Cummings, 2010)
15.4 = Average commute trip length by all modes (MCAQD, 2009)

[14] It is assumed that each carpool passenger reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

$$VER_1 = VMTR * [\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF)] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

$$VER_2 = VR * [\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + w4 * OFF_{PM}] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

where: ***ONF*** = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

$$Capital\ Recovery\ Factor\ (CRF) = \frac{(1+i)^{life}\ (i)}{(1+i)^{life}\ -1}$$

where: ***i*** = discount rate of 3 percent
life = program period of 1 year

$$Cost\text{-}Effectiveness = \frac{CRF * CMAQ\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Regional Rideshare Program **EXAMPLE**

RPTA requests $594,000 in FY 2015 CMAQ funds for the Regional Rideshare Program and indicates that the Regional Rideshare Program is responsible for ten percent of employee participation in carpooling. Based on interpolation of 2010 and 2020 projections adopted by the MAG Regional Council in May 2007, the total employment for Maricopa County in 2015 is expected to be 2,473,000.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = \$594,000.
- ***P*** = 10%.

Calculations:

$$\boldsymbol{VMTR} = \frac{0.11 * (1.6 * 2{,}473{,}000) * 0.10}{1.28} * 15.4 = 523{,}658$$

$$\boldsymbol{VR} = \frac{523{,}658}{15.4 * 1.6} = 21{,}252$$

$$\boldsymbol{VER_1} = 523{,}658 * (\frac{0.0 * 2.00}{4} + \frac{1.0 * 0.12}{2} + \frac{1.0 * 0.41}{2} + (1.0 * (0.04 + 0.26))) * \frac{1}{1000} * \frac{250}{365} = 202.65 \frac{kilograms}{day}$$

$$\boldsymbol{VER_2} = 21{,}252 * (\frac{0.0 * 4.16}{4} + \frac{1.0 * 0.48}{2} + \frac{1.0 * 0.26}{2} + (1.0 * (0.004))) * \frac{1}{1000} * \frac{250}{365} = 5.44 \frac{kilograms}{day}$$

$$Daily\ Emissions\ Reduction = 202.65 + 5.44 = 208.09 \frac{kilograms}{day}$$

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+0.03)^1 * (0.03)}{(1+0.03)^1 - 1} = 1.03$$

$$Cost\text{-}Effectiveness = \frac{1.03 * 594{,}000 * 1000}{208.09 * 365} = 8{,}055 \frac{dollars}{metric\ ton}$$

<u>TRAFFIC FLOW IMPROVEMENTS</u>

"Coordinate Traffic Signal Systems", "Develop Intelligent Transportation Systems", and "Reduce Traffic Congestion at Major Intersections" are committed control measures in the MAG 1999 Serious Area CO and PM-10 Plans. These measures reduce emissions by increasing vehicle speeds or reducing vehicle idling.

The 2005 CMAQ methodologies (MAG, 2005) stated that MAG would run the FHWA ITS Deployment Analysis System (IDAS) software to estimate the CO, TOG, and NOx emission reductions for Traffic Signal Coordination, Freeway Management System (FMS), and other Intelligent Transportation System (ITS) projects that are proposed for CMAQ funding. Unfortunately, application of IDAS did not provide the level of sensitivity needed to evaluate the emissions benefits of the types of traffic flow improvement projects typically proposed for MAG CMAQ funding.

In 2008, Sierra Research indicated that the level of detail used by the Texas Department of Transportation in evaluating CMAQ projects (TTI, 2007) is higher than currently required by the MAG methodologies. For example, the Texas Transportation Institute (TTI) methodology for ITS projects quantifies the emission reductions attributable to alleviating peak and off-peak recurrent and non-recurrent congestion.

To improve the methodologies used to evaluate traffic flow improvement projects proposed for CMAQ funding, MAG contracted with Lee Engineering and Texas Transportation Institute in early 2010. The new CMAQ methodologies recommended by Lee/TTI are described below (Lee/TTI, 2010). The recommended methodologies include four steps.

Step 1. Group individual project elements by Project.

Elements are individual projects in the MAG Transportation Improvement Program (TIP) that, when combined in a common geographic area, lead to implementation of a Project that reduces emissions. An example of three elements that lead to implementation of a Project is shown in Table 5.

Table 5 - Example of Three Elements Grouped into a Single Project

TIP Project	Description	FY
FED-08	Purchase and Install Malfunction Management Units in all Traffic Control Cabinets	2008
FED-09	Install Video Detection System	2009
FED-10	Design and Construct Fiber Optic Cable Installations	2010

Elements can also include planning and design projects. Note that elements are typically implemented over a number of years in the TIP. Rather than estimating benefits for each element, in the example above the three elements would be analyzed as one Project with benefits assigned to a geographic area (i.e., city, town, Indian community, or regionwide). It is possible to have elements that support multiple Projects (e.g., fiber optics). If elements do not belong to a single project group, they will be grouped by jurisdiction and the element with the highest emissions benefit will be used.

Lee/TTI recommended that MAG use an element grouping scheme that first grouped the elements by jurisdiction, then by level of improvement, then by market package as identified in the Regional ITS Architecture. Lee/TTI identified four levels of improvement: 1 = Citywide, 2 = Arterial, 3 = Intersection, and 4 = Central. Level 4 improvements represent elements that could have regional implications such as the connection to a regional Traffic Management Center. Lee/TTI also used the MAG Regional ITS Architecture to sub-group elements by market package. The final grouping, shown in Appendix A, will be updated to include new ITS projects, when they are submitted for CMAQ funding.

The MAG ITS Program staff will be responsible for assigning a proposed CMAQ project (element) to the appropriate Project Group. The MAG Environmental Division will calculate the emission benefits of the proposed ITS project, according to the Lee/TTI recommended approaches described below.

Step 2. Calculate the emissions benefit for each Project in the build year (i.e, the final year of grouped elements).

In calculating the emission benefits for traffic signal coordination projects, Lee/TTI recommends that MAG continue to use the speed-based approach used in previous MAG CMAQ methodologies. For other types of traffic flow improvements, Lee/TTI recommends use of the following new equations, derived from *The Texas Guide to Accepted Mobile Source Emission Reduction Strategies*, also called the MOSERS report (TTI, 2007).

For Incident Management Programs on Freeways:[15]

$$Daily\ Emission\ Reduction\ (grams/day) = E_{REG} * F_{NR} * \sum_{1}^{n} F_{EFF_i} * \frac{ADT_i}{ADT_T} \quad (MOSERS\ 1)$$

where: $\boldsymbol{ADT_i}$ = Average weekday traffic for each affected link
$\boldsymbol{ADT_T}$ = Total average weekday traffic for affected system (vehicles/day)
$\boldsymbol{E_{REG}}$ = Regional freeway emissions (grams)
$\boldsymbol{F_{Eff}}$ = Project effectiveness factor for each affected freeway[16]
$\mathbf{F_{NR}}$ = Nonrecurring emissions (decimal)[17]

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[15]Equation in Section 7.3 of the MOSERS report.

[16]From Section 7.3 of the MOSERS report: "The FHWA Southern Resource Center, August 1999, reports a 50% effectiveness rate for detection and response; 25% for motor assistance patrol; 15% for surveillance."

[17]From Section 7.3 of the MOSERS report: "According to the FHWA Southern Resource Center, August 1999 report, 4.9 percent of freeway emissions are caused by nonrecurring congestion."

For Regional/Systemwide Projects (e.g., Freeway Management System):[18]

$$Daily\ Emission\ Reduction\ (grams/day) = A + B + C + D \qquad (MOSERS\ 2)$$

A = Change in emissions from alleviating peak hour nonrecurrent congestion

$$A = E_P * F_{NR,P} * F_{ITS} * F_{EN,P}$$

B = Change in emissions from alleviating off-peak hour nonrecurrent congestion

$$B = E_{OP} * F_{OPH} * F_{NR,OP} * F_{ITS} * F_{EN,OP}$$

C = Change in emissions from alleviating peak hour recurrent congestion

$$C = E_P * F_{ITS} * (1 - F_{NR,P}) * F_{ER,P}$$

D = Change in emissions from alleviating off-peak hour recurrent congestion

$$D = E_{OP} * F_{OPH} * F_{ITS} * (1 - F_{NR,OP}) * F_{ER,OP}$$

where:

$\boldsymbol{E_{OP}}$ = Emissions generated by congestion on affected roadway system during the off-peak period for each pollutant (CO, TOG, NOx, PM-10) in grams

$\boldsymbol{E_{P}}$ = Emissions generated by congestion on affected roadway system during the peak period for each pollutant (CO, TOG, NOx, PM-10) in grams

$\boldsymbol{F_{EN,OP}}$ = Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, off-peak period (decimal)

$\boldsymbol{F_{EN,P}}$ = Percent of nonrecurrent congestion eliminated on roadways with ITS deployment, peak period (decimal)

$\boldsymbol{F_{ER,OP}}$ = Percent of recurrent congestion eliminated on roadways with ITS deployment, off-peak period (decimal)

[18] Equation 2 in Section 7.4 of the MOSERS report.

$F_{ER,P}$ = Percent of recurrent congestion eliminated on roadways with ITS deployment, peak period (decimal)
F_{ITS} = Percent of roadway system coverage with ITS deployment (decimal)
$F_{NR,OP}$ = Percent of roadway system emissions caused by nonrecurring congestion in the off-peak period (decimal)
$F_{NR,P}$ = Percent of roadway system emissions caused by nonrecurring congestion in the peak period (decimal)
F_{OPH} = Percent of off-peak hour emissions affected by ITS deployment (decimal)

For All Other Traffic Flow Improvement Projects:[19]

$$\textit{Daily Emission Reduction (grams/day)} = \sum_{1}^{n} [L_i * AADT_i * (EF_B - EF_A)_i] \quad (\textit{MOSERS } 3)$$

where: $AADT_i$ = Annual average daily traffic for each affected roadway (for freeways, multiply average weekday traffic (ADT) by 0.92; for arterials multiply ADT by 0.93)
EF_A = Speed-based running exhaust emission factor after implementation (CO, TOG, NOx, or PM-10) in grams per mile
EF_B = Speed-based running exhaust emission factor before implementation (CO, TOG, NOx, or PM-10) in grams per mile
L_I = Length of each freeway or arterial affected by ITS (miles)
N = Number of affected corridors

Lee/TTI recommended that the MOSERS 3 equation be used for all ITS projects until results of the ongoing MAG study on nonrecurring congestion become available. The MAG study will provide local values for many of the variables in MOSERS equations 1 and 2 (e.g., F_{NR}, the percent of roadway system emissions caused by nonrecurring congestion). Until these local data become available, MAG will apply the MOSERS 3 equation to evaluate all ITS projects that are proposed for CMAQ funding. MAG Environmental Division staff will calculate the emission reductions for each element of the Project Group in order to identify the element with the maximum benefit.

Step 3. Allocate the maximum emissions benefit of the Project to elements in the same group based on the vehicle miles of travel (VMT) calculated for each element.

The emission reductions will be allocated to each element in proportion to the VMT calculated for that element. Lee/TTI indicated that this approach allocates unrealistically high emission benefits to plans and studies because they typically cover large geographic areas and have high VMT levels. To offset this effect, MAG Environmental Division staff will assign five percent of the maximum benefit of the Project to ITS planning and study elements.

[19]Equation 1 in Section 7.4 of MOSERS report.

Step 4. Apply the current MAG pollutant weighting and develop cost effectiveness ranking.

Lee/TTI recommended that cost effectiveness be calculated in the same way as in the 2009 MAG CMAQ methodologies (MAG, 2009). The Lee/TTI recommendations are described for each type of traffic flow improvement project in the sections below.

<u>Traffic Signal Coordination</u>

MOVES will be run to calculate the daily CO, TOG, NOx, and PM-10 emission reductions attributable to traffic signal coordination projects. The information in Table 6 was obtained from the California Air Resources Board (CARB, 2005). The length of the project, the ADT, the pre-project speed, and the category in Table 6 that best represents the proposed project will be provided by the agency requesting CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Length of project (***miles***).
- Current average weekday traffic (***ADT***).
- Pre-project speed.
- The category into which the proposed project should be classified (see Table 6).

Table 6. Traffic Signal Coordination - Post-Project Speeds

Category	Before Condition	After Condition	Increase in Speed
one	Non-interconnected, pre-timed signals with old timing plan	Advanced computer-based control	25%
two	Interconnected, pre-timed signals with old timing plan	Advanced computer-based control	17.5%
three	Non-interconnected signals with traffic-actuated controllers	Advanced computer-based control	16%
four	Interconnected, pre-timed signals with actively managed timing	Advanced computer-based control	8%
five	Interconnected, pre-timed signals with various forms of master control and various qualities of timing plans	Optimization of signal timing plans. No change in hardware	12%
six	Non-interconnected, pre-timed signals with old timing plan	Optimization of signal timing plan	7.5%

Formulas:

$$Daily\ Emissions\ Reduction = \boldsymbol{miles} * \boldsymbol{ADT} * \mathbf{0.93} *$$

$$[(\frac{w1*BEF_{CO}}{4}+\frac{w2*BEF_{TOG}}{2}+\frac{w3*BEF_{NOx}}{2}+w4*BEF_{PM})-(\frac{w1*AEF_{CO}}{4}+\frac{w2*AEF_{TOG}}{2}+\frac{w3*AEF_{NOx}}{2}+w4*AEF_{PM}]*\frac{1}{1000}=\frac{kg}{day}$$

where: ***miles*** = the length of the project
ADT = the average weekday traffic
0.93 = the factor for converting ADT to annual average daily traffic on arterials
BEF = the emission factor for all vehicle classes at the pre-project speed
AEF = the emission factor at the post-project speed (from Table 6)
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}}-1}$$

where: ***i*** = discount rate of 3 percent
life = effectiveness period of 5 years (CARB, 2005)

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Traffic Signal Coordination — EXAMPLE

A city proposes to install a system in FY 2015 that synchronizes the traffic lights on three miles of street. The city will be replacing interconnected, pre-timed signals with actively managed timing with an advanced computer-based control system. The cost of the system is $150,000. The city proposes to pay $15,000 and requests $135,000 of CMAQ funding. The average speed on the three miles of street is estimated to be 25 mph. Since the project falls within category four in Table 6, the post-improvement speed will be eight percent higher than 25 mph or 27 mph. The weekday traffic on the road is estimated to be 10,000 vehicles per day.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = \$135,000.
- Length of project (***miles***) = 3.
- Average weekday traffic (***ADT***) = 10,000.
- The pre-project speed = 25 mph.
- The category into which the proposed project is classified (from Table 6) = four

Calculations:

$$\textit{Daily Emissions Reduction} = 3*(10{,}000*0.93)*[(\frac{0.0*4.94}{4}+\frac{1.0*0.17}{2}+\frac{1.0*0.65}{2}+1.0*0.06) -$$

$$\frac{0.00*4.74}{4} + \frac{1.0*0.16}{2} + \frac{1.0*0.61}{2} + 1.0*0.05)] * \frac{1}{1000} = 0.98 \; \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 135{,}000 * 1000}{0.98 * 365} = 82{,}427 \; \frac{\textit{dollars}}{\textit{metric ton}}$$

<u>Intelligent Transportation Systems</u>

The installation of Intelligent Transportation Systems (ITS) alerts drivers concerning congestion incidents. Incident management projects permit more efficient re-routing of traffic and reduce vehicle idling which, in turn, reduces emissions. Freeway Management System projects improve the traffic flow on the regional system of freeways. Other ITS projects improve the traffic flow on arterials. Until local values for the MOSERS 1 and 2 equations are obtained, Lee/TTI recommends that MOSERS 3 be applied to calculate the emission reduction benefits of all proposed ITS projects. The MAG ITS Program will assign the proposed ITS project (element) to the appropriate Project Group. The MAG Environmental Division will calculate the emission benefits of each element in the Project Group in order to identify the maximum benefit among the elements. The maximum benefit will be apportioned based on the share of VMT associated with the proposed project element relative to the total VMT of all elements in the Group. If there are multiple corridors involved in an ITS project, then the formula would be applied to each corridor and the emissions benefits would be summed.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Length of project (***miles***).
- Average weekday traffic (***ADT***).
- The pre-project speed.
- The post-project speed.

Formulas:

$$Daily\ Emissions\ Reduction = \boldsymbol{miles} * \boldsymbol{AADT} *$$

$$[(\frac{w1*BEF_{CO}}{4}+\frac{w2*BEF_{TOG}}{2}+\frac{w3*BEF_{NOx}}{2}+w4*BEF_{PM})-(\frac{w1*AEF_{CO}}{4}+\frac{w2*AEF_{TOG}}{2}+\frac{w3*AEF_{NOx}}{2}+w4*AEF_{PM}]*\frac{1}{1000}=\frac{kg}{day}$$

where: ***miles*** = the length of the project

AADT = the annual average daily traffic (for freeways, multiply average weekday traffic (ADT) by 0.92; for arterials, multiply ADT by 0.93*)*

BEF = the emission factor for all vehicle classes at the pre-project speed

AEF = the emission factor for all vehicle classes at the post-project speed

w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}}\ -1}$$

where: ***i*** = discount rate of 3 percent

life = effectiveness period of 5 years

$$Cost-Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ\ Cost} * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Intelligent Transportation Systems EXAMPLE

A city proposes to design and construct fiber optic cable installations in FY 2015. The MAG ITS Program determines that the project is an element of a larger Project Group for the same city that includes ITS projects that have already been approved for CMAQ funding in FY 2013 and FY 2014. The city estimates that the implementation of all elements in the Project Group will increase weekday vehicle speeds from 25 to 27 mph on 30 miles of arterials. The affected arterials carry an average of 10,000 vehicles per average weekday. The cost of the project is $150,000. The city proposes to pay $15,000 and is requesting $135,000 in CMAQ funding.

The MAG Environmental Division determines that this project element represents half of the total VMT for all elements in the Project Group. Therefore, the emission reduction benefits of this proposed project are reduced by 50 percent in the calculations below.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = $135,000.
- Length of project (***miles***) = 30.
- Average weekday traffic (***ADT***) = 10,000.
- The pre-project speed = 25 mph.
- The post-project speed = 27 mph.

Calculations:

$$\textit{Daily Emissions Reduction} = 30*(10{,}000*0.93)*[(\frac{0.0*4.94}{4}+\frac{1.0*0.17}{2}+\frac{1.0*0.65}{2}+1.0*0.06) -$$

$$\frac{0.00*4.74}{4} + \frac{1.0*0.16}{2}+\frac{1.0*0.61}{2} + 1.0*0.05)] * \frac{1}{1000} * 0.5 = 4.88 \ \frac{\textit{kilograms}}{\textit{day}}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^5 * (0.03)}{(1+0.03)^5 - 1} = 0.2184$$

$$\textit{Cost-Effectiveness} = \frac{0.2184 * 135{,}000 * 1000}{4.88 * 365} = 16{,}553 \ \frac{\textit{dollars}}{\textit{metric ton}}$$

TRIP REDUCTION PROGRAM

"Trip Reduction Program" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. The Trip Reduction Program requires employers with 50 or more employees at a work site in Area A to achieve target reductions in single occupant vehicle (SOV) trips through use of alternate transportation modes. Alternate transportation modes include carpooling, vanpooling, taking the bus, bicycling, and walking. Reductions in SOV trips due to telecommuting or compressed work schedules also qualify for credit in the trip reduction program. The program reduces emissions by decreasing the total vehicle miles of travel (VMT) for commute trips.

The Maricopa County Trip Reduction Program (TRP) maintains detailed information on participating organizations and their employees and students. In 2009, TRP data (MCAQD, 2009) indicates that 32 percent of employees work for TRP organizations and 24 percent of the commute trips taken by these employees are by alternate modes (or the commute trip is eliminated, in the case of telecommuting and compressed work weeks). In addition, the 89,000 Maricopa County students participating in the TRP in 2009 made 54 percent of their trips by alternate modes. The 2009 TRP data also indicates that the average one-way trip length for TRP participants (both employees and students) is 14.7 miles. The average vehicle occupancy for all modes in 2009 was 1.28 (Cummings, 2010).

The MOVES model will be run for the CMAQ funding year to estimate the onroad (Road Types 2-5) light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, and ONF_{PM}). The paved road emission factor for all roads of 0.26 grams per mile will be added to ONF_{PM}. MOVES will also be run to generate off-network (Road Type 1) light duty vehicle emission factors for each pollutant (OFF_{CO}, OFF_{TOG}, OFF_{NOx}, *and* OFF_{PM}).[20] The onroad emission factors will be multiplied by vehicle miles of travel, while the off-network emission factors will be multiplied by the vehicles reduced. These emission reductions will be summed to estimate the total benefit of the Trip Reduction Program.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.
- Percent of alternate mode use attributable to the Trip Reduction Program (***P***).
- Total employment in Maricopa County in the CMAQ funding year (***TE***).
- Students participating in the TRP program in the CMAQ funding year (***ST***).

Formulas:

$$\textit{VMT Reduced}\ (\boldsymbol{VMTR}) = \frac{((\mathbf{0.24} * (\mathbf{1.6} * \boldsymbol{TE}) * \mathbf{0.32}) + (\mathbf{0.52} * (\mathbf{0.27} * ST))) * P}{\mathbf{1.28}} * \mathbf{14.7}$$

$$\textit{Vehicles Reduced}\ (\boldsymbol{VR}) = \frac{\boldsymbol{VMTR}}{\mathbf{1.6} * \mathbf{14.7}}$$

where: **0.24** = percent of TRP employee commute trips using alternate modes, including telecommuting and compressed work schedules (Cummings, 2010)
1.6 = factor to convert employment to weekday work trips (from MAG trip attraction equation)
TE = Total Maricopa County employment in funding year (from MAG projections)
0.32 = percent of employees participating in the TRP (Cummings, 2010)
0.52 = percent of TRP student trips using alternative modes (Cummings, 2010)
0.27 = factor to convert students into weekday trips (1/6 of the work trip rate of 1.6)

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[20]It is assumed that each trip reduced by the Trip Reduction Program reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

ST = students in Maricopa County participating in the TRP in the funding year (default = 89,000 in 2009)
P = percent of alternate mode use attributable to the TRP
1.28 = average vehicle occupancy (Cummings, 2010)
14.7 = average one-way trip length to work or school (MCAQD, 2009)

$$\boldsymbol{VER_1} = VMTR * [\frac{w1 * ONF_{CO}}{4} + \frac{w2 * ONF_{TOG}}{2} + \frac{w3 * ONF_{NOx}}{2} + w4 * (ONF_{PM} + PEF)] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

$$\boldsymbol{VER_2} = VR * [\frac{w1 * OFF_{CO}}{4} + \frac{w2 * OFF_{TOG}}{2} + \frac{w3 * OFF_{NOx}}{2} + (w4 * OFF_{PM})] * \frac{1}{1000} * \frac{250}{365} = \frac{kilograms}{day}$$

$$Daily\ Emissions\ Reduction = \boldsymbol{VER_1} + \boldsymbol{VER_2} = \frac{kilograms}{day}$$

where: ***ONF*** = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)
w1-w4 = weighting factors for CO, TOG, NOx, and PM-10, respectively
250/365 = factor to convert from an average weekday to an annual average day

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}} - 1}$$

where: ***i*** = discount rate of 3 percent
life = program period of 1 year

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

Maricopa County requests \$910,000 in FY 2015 CMAQ funds for the Trip Reduction Program. The Arizona Department of Environmental Quality contributes \$948,000 to the program. The County estimates that the share of alternative mode use attributable to the Trip Reduction Program is 25 percent. The County also indicates that the number of students expected to participate in the TRP in 2015 is 100,000. Based on interpolation of 2010 and 2020 projections adopted by the MAG Regional Council in May 2007, the total employment for Maricopa County in 2015 is expected to be 2,473,000.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = \$910,000.
- ***P*** = 25%.
- ***TE*** = 2,473,000.
- ***ST*** = 100,000.

Calculations:

$$\textit{VMT Reduced } (\boldsymbol{VMTR}) = \frac{((0.24*(1.6*2{,}473{,}000)*0.32) + (0.52*(.27*100{,}000))*0.25}{1.28} * 14.7 = 912{,}784$$

$$\textit{Vehicles Reduced } (\boldsymbol{VR}) = \frac{912{,}784}{1.6 * 14.7} = 38{,}809$$

$$\boldsymbol{VER_1} = 912{,}784*(\frac{0.0*2.00}{4}+\frac{1.0*0.12}{2}+\frac{1.0*0.41}{2}+(1.0*(0.04+0.26)))*\frac{1}{1000}*\frac{250}{365} = 353.23\ \frac{kilograms}{day}$$

$$\boldsymbol{VER_2} = 38{,}809*(\frac{0.0*4.16}{4}+\frac{1.0*0.48}{2}+\frac{1.0*0.26}{2}+(1.0*0.004))*\frac{1}{1000}*\frac{250}{365} = 9.94\ \frac{kilograms}{day}$$

$$\textit{Daily Emissions Reduction} = 353.23 + 9.94 = 363.17\ \frac{kilograms}{day}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^1 * (0.03)}{(1+0.03)^1 - 1} = 1.03$$

$$\textit{Cost-Effectiveness} = \frac{1.03 * 910{,}000 * 1000}{363.17 * 365} = 7{,}071\ \frac{dollars}{metric\ ton}$$

VANPOOL VEHICLES

"Encouragement of Vanpooling" is a committed control measure in the MAG 1999 Serious Area CO and PM-10 Plans. Vanpools reduce emissions by decreasing the total vehicle miles of travel for commute trips.

Valley Metro estimates that the average vanpool vehicle travels 66 miles (on average - round trip) per day on 255 commute days per year. This is equivalent to 16,830 commute miles annually per van. Valley Metro also estimates that the average vanpool carries nine people, including the driver. The average commute trip length per vanpool rider is 24.1 miles one-way (MCAQD, 2009). Therefore, the daily commute miles (round trip) saved per vanpool occupant is 48.2. Assuming that all nine of the vanpool occupants would have driven in single-occupant vehicles (SOV), the vehicle miles of travel replaced by a vanpool is 93,789 ((9 x 48.2 x255) - 16,830). The comparable number of vehicles reduced by each vanpool annually is 2,040 (8 passengers times 255 commute days).

The MOVES model will be run for the year that the CMAQ funds are requested to estimate the onroad (MOVES Road Types 2-5) light duty vehicle emission factors for CO, TOG, NOx, and PM-10 (ONF_{CO}, ONF_{TOG}, ONF_{NOx}, and ONF_{PM}) and the off-network vehicle emission factors (MOVES Road Type 1) for each pollutant (OFF_{CO}, OFF_{TOG}, OFF_{NOx}, and OFF_{PM}).[21] Emission factors for onroad vans ($VONF_{CO}$, $VONF_{TOG}$, $VONF_{NOx}$, and $VONF_{PM}$) and off-network vans ($VOFF_{CO}$, $VOFF_{TOG}$, $VOFF_{NOx}$, and $VOFF_{PM}$) will also be estimated using MOVES. The paved road emission factor (*PEF*) for all roads of 0.26 grams per mile will be added to $ONF_{PM.}$ and $VONF_{PM.}$ The *ONF* and *VONF* emission factors will be multiplied by the appropriate vehicle miles of travel. The *OFF* and *VOFF* emission factors will be multiplied by the number of vehicles reduced. The difference between the commute emissions reduced and the vanpool emissions will represent the net benefit of vanpools.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost***.

Formulas:

$$\textit{VMT Emissions Reduced } (\boldsymbol{VMTR}) = \boldsymbol{VMT} * \left(\frac{w1*ONF_{CO}}{4}+\frac{w2*ONF_{TOG}}{2}+\frac{w3*ONF_{NOx}}{2}+w4*(ONF_{PM}+PEF)\right)*\frac{1}{1000}$$

$$\textit{Vehicle Emissions Reduced } (\boldsymbol{VR}) = \boldsymbol{vehicles} * \left(\frac{w1*OFF_{CO}}{4}+\frac{w2*OFF_{TOG}}{2}+\frac{w3*OFF_{NOx}}{2}+(w4*OFF_{PM})\right) * \frac{1}{1000}$$

[21] It is assumed that each vanpool passenger reduces off-network emissions (i.e., cold start, hot soak and evaporative emissions) by one vehicle hour between 6 a.m. and 6 p.m.

where: ***VMT*** = the vehicle miles of travel replaced by the vanpool each year (93,789)
vehicles = the number of light duty vehicles replaced by the vanpool each year (2,040)
ONF = the onroad light duty vehicle emission factor for each pollutant
OFF = the off-network light duty vehicle emission factor for each pollutant
PEF = the paved road PM-10 emission factor for all road types (0.26 g/mi)

$$Vanpool\ Emissions\ (\boldsymbol{VE}) = [(\boldsymbol{miles_{vanpool}} * (\frac{w1*VONF_{CO}}{4} + \frac{w2*VONF_{TOG}}{2} + \frac{w3*VONF_{NOx}}{2} + w4*(VONF_{PM} + PEF))) +$$

$$(days_{vanpool} * (\frac{w1*VOFF_{CO}}{4} + \frac{w2*VOFF_{TOG}}{2} + \frac{w3*VOFF_{NOx}}{2} + w4*VOFF_{PM}))] * \frac{1}{1000}$$

where: ***miles*** $_{\mathbf{vanpool}}$ = the miles driven annually by a van used as a vanpool (16,830)
ONF = the onroad emission factors for a van for each pollutant
days $_{\mathbf{vanpool}}$ = the days driven annually by a van used as a vanpool (255)
OFF = the off-network emission factors for a van for each pollutant

$$Daily\ Emissions\ Reduction = N * (\boldsymbol{VMTR} + \boldsymbol{VR} - \boldsymbol{VE}) * \frac{1}{365} = \frac{kilograms}{day}$$

where: ***N*** = the number of vans being purchased
1/365 = factor to convert annual emissions to daily emissions

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{(1+i)^{\boldsymbol{life}}\ (i)}{(1+i)^{\boldsymbol{life}} - 1}$$

where: ***i*** = discount rate of 3 percent
lif*e* = effectiveness period of 4 years

$$Cost\text{-}Effectiveness = \frac{\boldsymbol{CRF} * \boldsymbol{CMAQ}\ Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: ***CMAQ Cost*** = the CMAQ funding requested for the project.

RPTA proposes to purchase a fifteen-passenger van to be used in a vanpool. The cost of the van is \$25,000. RPTA requests \$25,000 of FY 2015 CMAQ funding.

Inputs Required from Entity Requesting CMAQ Funds:

- ***CMAQ Cost*** = \$25,000.

Calculations:

$$\textit{VMT Emissions Reduced } (\boldsymbol{VMTR}) = 93{,}789 * \left(\frac{0.0*2.00}{4}+\frac{1.0*0.12}{2}+\frac{1.0*0.41}{2}+(1.0*(0.04+0.26)\right)*\frac{1}{1000} = 52.99\ \frac{kg}{yr}$$

$$\textit{Vehicle Emissions Reduced } (\boldsymbol{VR}) = 2{,}040 * \left(\frac{0.0*4.16}{4}+\frac{1.0*0.48}{2}+\frac{1.0*0.26}{2}+(1.0*0.004)\right)*\frac{1}{1000} = 0.76\ \frac{kg}{yr}$$

$$\textit{Vanpool Emissions } (\boldsymbol{VE}) = (16{,}830 * \left(\frac{0.0*2.74}{4}+\frac{1.0*0.19}{2}+\frac{1.0*0.67}{2}+(1.0*(0.05+0.26))\right) +$$

$$255 * \left(\frac{0.0*6.18}{4}+\frac{1.0*0.67}{2}+\frac{1.0*0.39}{2}+(1.0*0.005)\right))*\frac{1}{1000} = 12.59\ \frac{kg}{yr}$$

$$\textit{Daily Emissions Reduction} = 1 * (52.99 + 0.76 - 12.59) * \frac{1}{365} = 0.11\ \frac{kg}{day}$$

$$\textit{Capital Recovery Factor } (\boldsymbol{CRF}) = \frac{(1+0.03)^4 * (0.03)}{(1+0.03)^4 - 1} = 0.2690$$

$$\textit{Cost-Effectiveness} = \frac{0.269 * 25{,}000 * 1000}{0.11 * 365} = 167{,}497\ \frac{dollars}{metric\ ton}$$

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